AMS02-ECAL FEM Model Correlation

October 15, 2003

ABSTRACT

In this report, the AMS-02 ECAL Finite Element Model is created. The Space Qualification test results of the Sine-Sweep test and Sine-Burst test are described. Based on the test data, the FEM model correlation work is fulfilled here. By optimizing the parameters of the CBAR element which is used to simulate the spring foam between the Pancake and ECAL structure, the first 3 fundamental frequencies are in good agreement with the Sine Sweep test data. By optimizing the damping coefficients, the Maximum Principle stresses are relatively in good agreement with the Sine-Burst test data on the most sensors position. According to the work above, a correlated ECAL FEM model has been obtained which can be used for the flight load cases simulation of the structure design and for the further weight saving analysis later.

Content

1 INTRODUCTION

The Electromagnetic Calorimeter (ECAL) is a sub-detector of Alpha Magnetic Spectrometer(AMS02). The ECAL configuration is shown in Fig. 1. The ECAL structure consists of 2 Honeycomb Plates, 4 Sidepanels (2 sidepanels have 4 rows of PMT holes, the other 2 sidepanels have 5 rows of PMTs holes), 4 Brackets, 4 Support Beams. Each component is connected by fasteners to form a box-like structure. The so called Pancake is the detector part, which mainly made of Lead sheets interleaf with scintillation fibers, is located inside the box of the ECAL structure. There are 2 Honeycomb Pads of about 14.5mm thickness between the Honeycomb Plate and the upper/lower Pancake Surfaces. And there are Springfoams of about 2~2.5mm thickness between the Pancake and the ECAL structure components. The ECAL sub-detector is connected to the Unique Support Structure –02(USS-02) by the bolts in support beams so that the inertial loads bore by ECAL is transferred to USS-02.

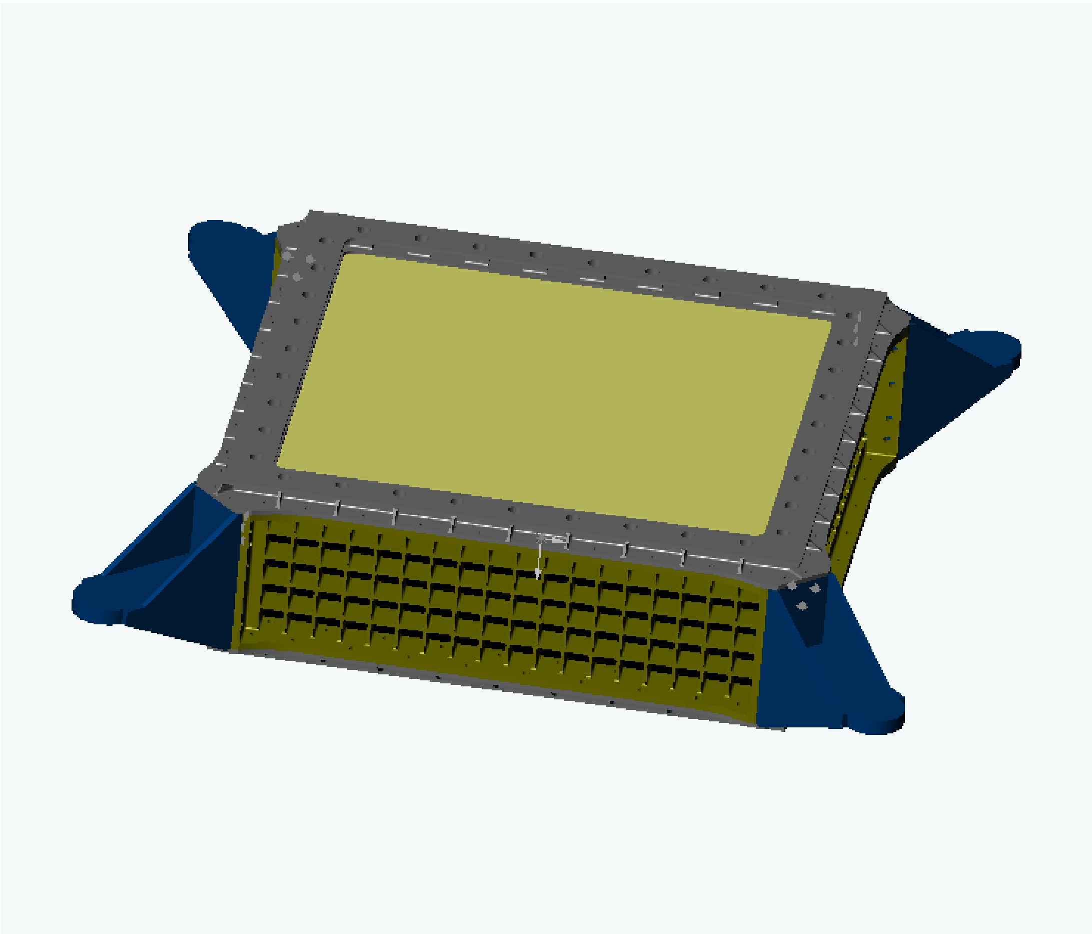


Fig. 1-1 Configuration of ECAL

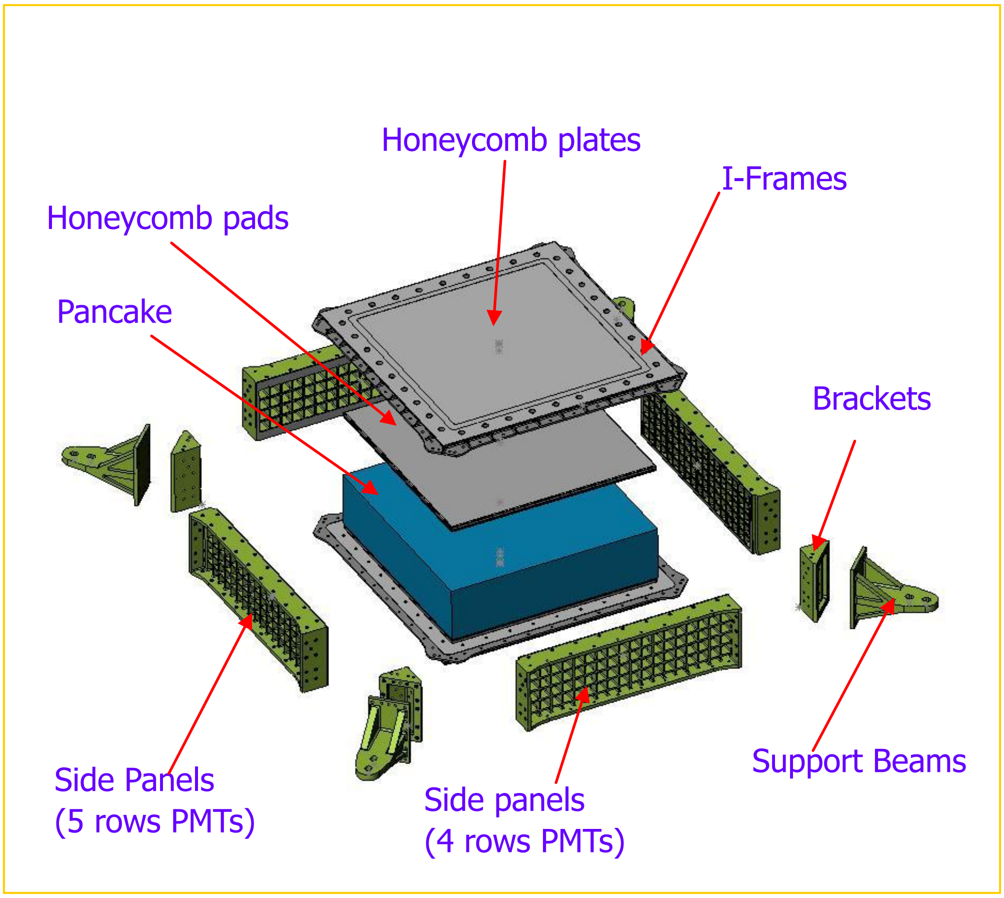


Fig. 1-2 Explode view of ECAL

The ECAL Space Qualification test was done in Beijing in January 2003. Sine-Sweep test, Random Vibration test, and the Sine Burst test were fulfilled according to the test level required in AMS-02 Structure Verification Plane.

Due to the need of the AMS-02 phase II safety review and the ECAL weight saving calculation, it's essential for the FEM model to be correlated to have better agreement between the calculation results and the test results.

In the paper, the AMS-02 ECAL Finite Element Model is created. The Space Qualification test results of the Sine-Sweep test and Sine-Burst test are described. By optimizing the parameters of the CBAR element which is used to simulate the spring foam between the Pancake and ECAL structure, the first 3 fundamental frequencies are in good agreement with the Sine Sweep test data. By optimizing the damping coefficients, the Maximum Principle stresses are relatively in good agreement with the Sine-Burst test data on the most sensors position. A correlated ECAL FEM model has been obtained and can be used for the flight load case simulation and ECAL weight saving calculation later.

2 DESCRIPTION OF FEM MODEL

2.1 FEM Group

The Finite Element Method (FEM) analysis of AMS-02 ECAL structure is done by MSC/PATRAN and MSC/NASTRAN software. The ECAL FEM Model includes 49966 GRIDs, 2652 CBAR Elements, 4097 CHEXA Elements, 39246 CQUAD4 Elements, 11602 CTRIA3 Elements, 32 MPCs.

The ECAL FEM Model is shown in Fig 2.1. In MSC/PATRAN, each component of the FEM model is created separately. Different components are managed in different Group. They are listed in Table 2.

This FEM model can be used for the Static Analysis, Natural Frequency (Normal Mode) Analysis, Sine-Burst Test Prediction Analysis. But different Analysis Groups are collected to do different analysis separately. This will be illustrated in detail in chapter 2.8 later.

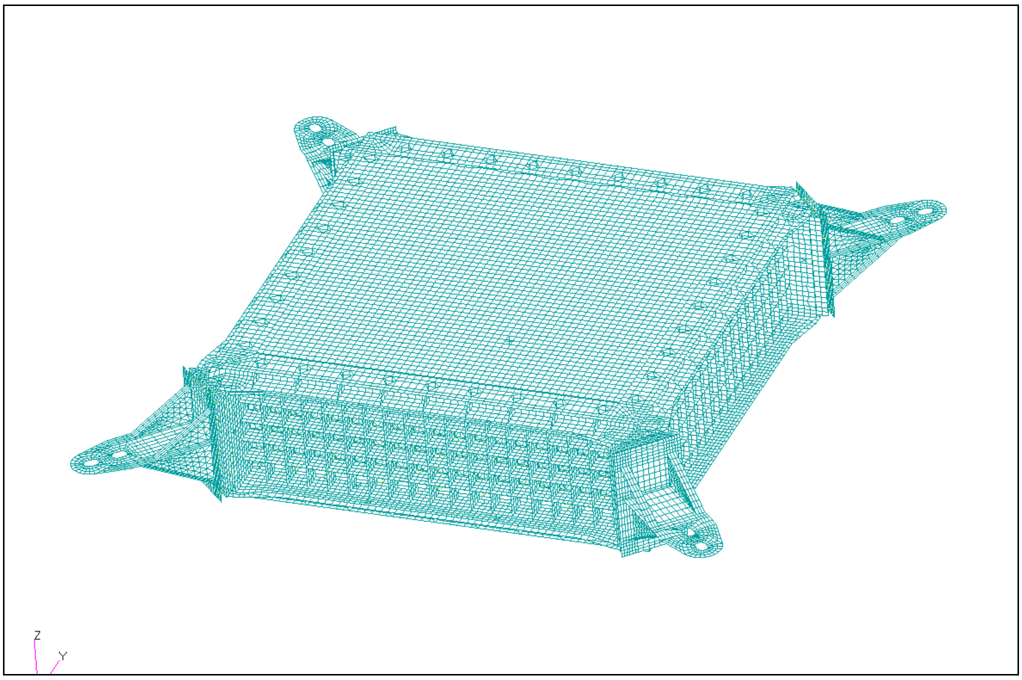


Fig 2.1 ECAL FEM Model (Overall)

Table 2 FEM group in PATRAN for ECAL components

No.	Group Name	Real Structure Component	Element Description	Nodes No.	Elements No.	Remarks
1	Side-panel	4 Side Panels	CQUAD4	1:9950 10001:18986	1:9178 10001:18292	
2	I-Frame	2 I Frame of Honeycomb structures	CQUAD4 CTRIA3	20001:23444 26714:30157	23073:27188 30261:34376	
3	Honeycomb-Plate	2 Honeycomb Plates	CQUAD4,CTRIA3	23445:26713 30158:33426	20001:23072 27189:30260	PCOMP element property
4	Honeycomb-Pad	2 Honeycomb Pads	CQUAD4	40001:41568	40001:41458	PCOMP element property
5	Bracket	4 brackets	CQUAD4 CTRIA3	50001:52364	50001:52928	
6	Support	4 support beams	CQUAD4 CTRIA3	55001:59520	55001:60096	
7	Pancake	Pancake	CHEXA CQUAD4,CTRIA3	70001:79120	70001:74097 75001:84520	Solid elements used inside, with shell elements enveloped on the outside surfaces so as to connect with CBAR elements.

Table 2 FEM group in PATRAN for component structure

	Group Name	Real Structure	Element Description	Nodes No.	Elements No.	Remarks
8	Bar-pancake-X		CBAR	-	90001:90378 90501:90878	Connecting Pancake's X direction surface and ECAL corresponding sidepanel.
9	Bar-pancake-Y		CBAR	-	91001:91396 91501:91896	Connecting Pancake's Y direction surface and ECAL corresponding sidepanel.
10	Bar-Honey pad-Z		CBAR	-	92001:92196 93001:93196	Connecting Pancake and Honey pad
11	Bar-Honey plate-Z		CBAR	-	94001:94196 95001:95196	Connecting Honey plate and Honey pad
12	bolt-bracket-Ifame		CBAR	-	120001:120032 Mpc 9:24	Bolts and shear pins between IFrame and Bracket
13	bolt-bracket-support		MPC BRE2	-	130001:130064 Mpc 25:32	Bolts and shear pins between Bracket and Support
14	bolt-iframe-sidepanel		MPC BRE2	-	100001:100152	Bolts between Sidepanel and Bracket
15	bolt-sidepanel-bracket		MPC BRE2	-	140001:140072	Bolts between Bracket and Support
16	MPC-USS2		MPC BRE2	-	MPC 1:8	Bolts between support and USS2

2.2 Coordinate System

The ECAL FEM model is located in the Global Coordinate System. The OX, OY, OZ axes are the same as defined in the AMS-02 SVP for the ECAL structure. The C.G of the ECAL FEM model is located in the (0, 0, 0) of the Global Coordinate System.

In order to add Boundary Conditions on the ECAL FEM model, a local rectangular coordinate (Coord 1) is created. The relationship of local coordinate systems and the global system are shown in Fig 2.2.

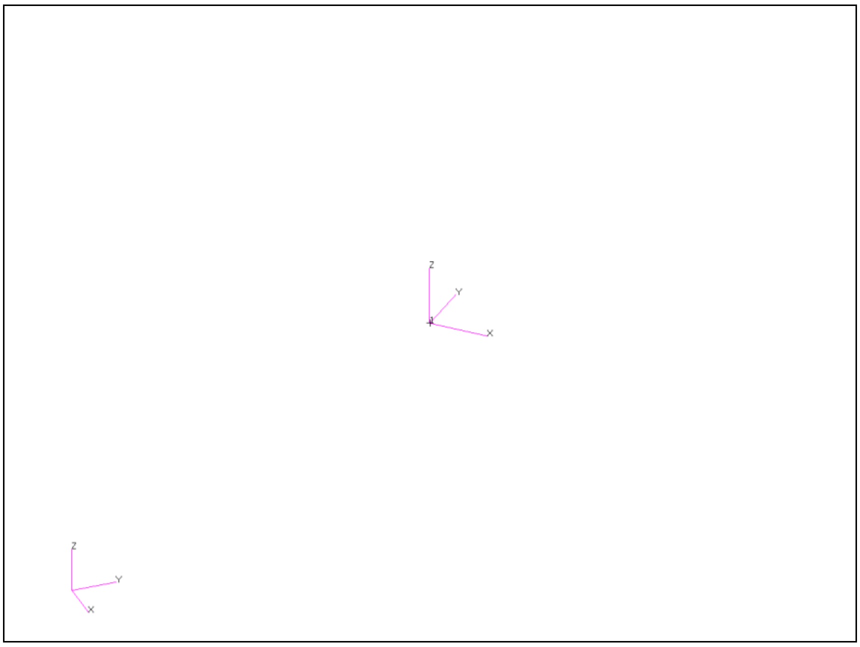


Fig 2.2 Relation between Local Coordinate Systems and Global Coordinate System

2.3 FEM mesh for component structure

There are 7 groups for the component structure as shown in Table 2. The FEM Meshs are shown in Fig. 2.3~2.14.

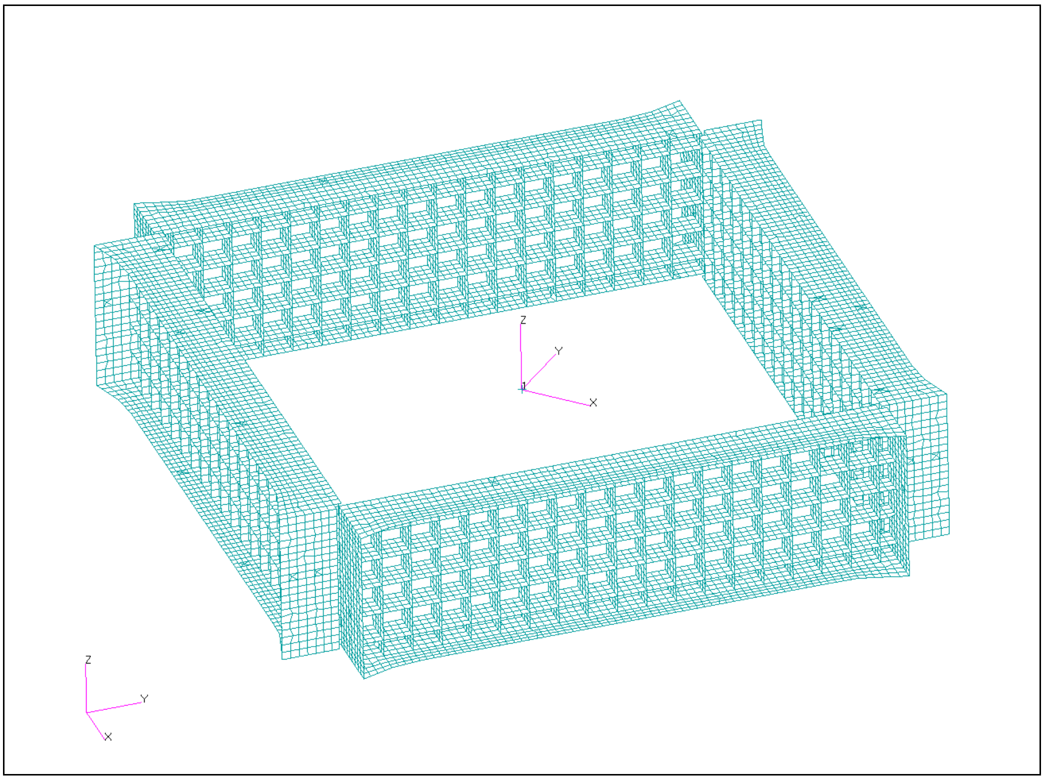


Fig 2.3 FEM Mesh in group Side-Panel

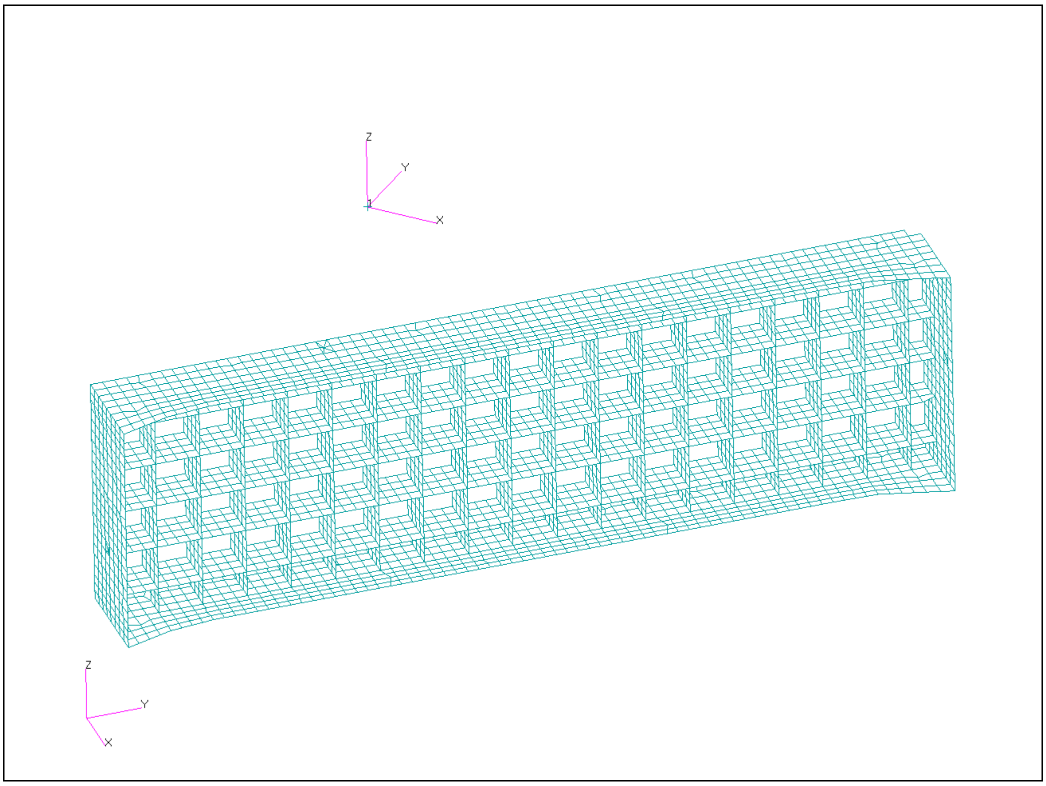


Fig 2.4 FEM Mesh in group Side-Panel(only one sidepanel)

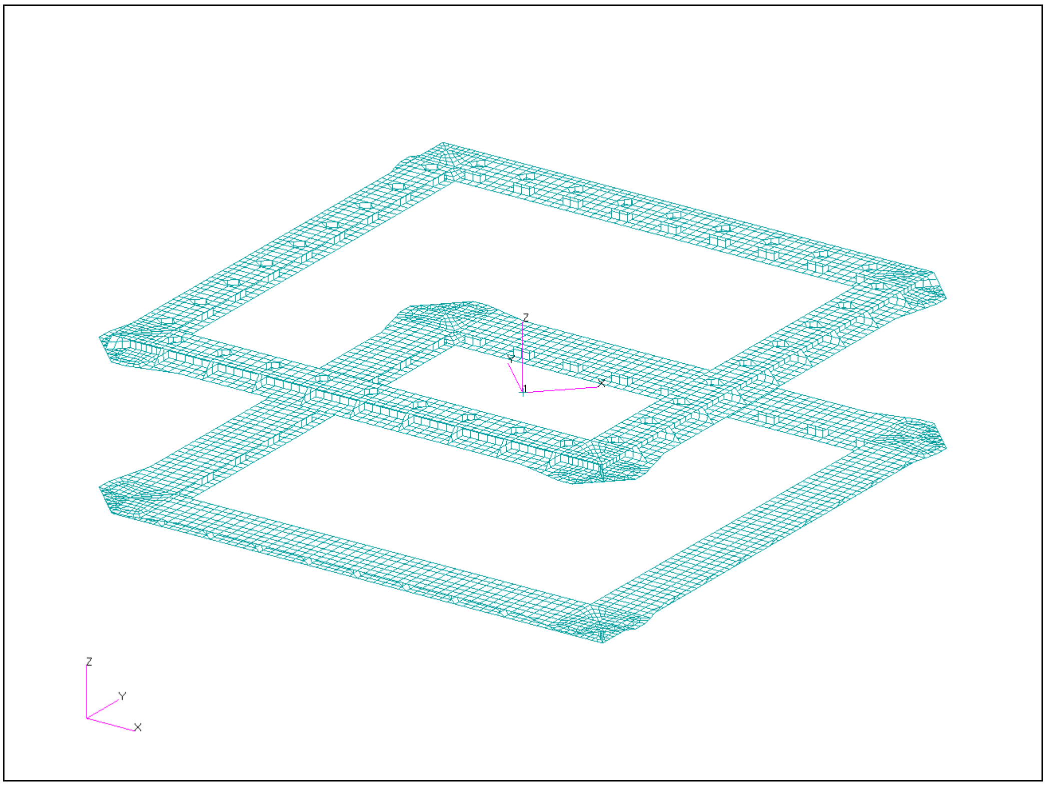


Fig 2.5 FEM Mesh in group I-Frame

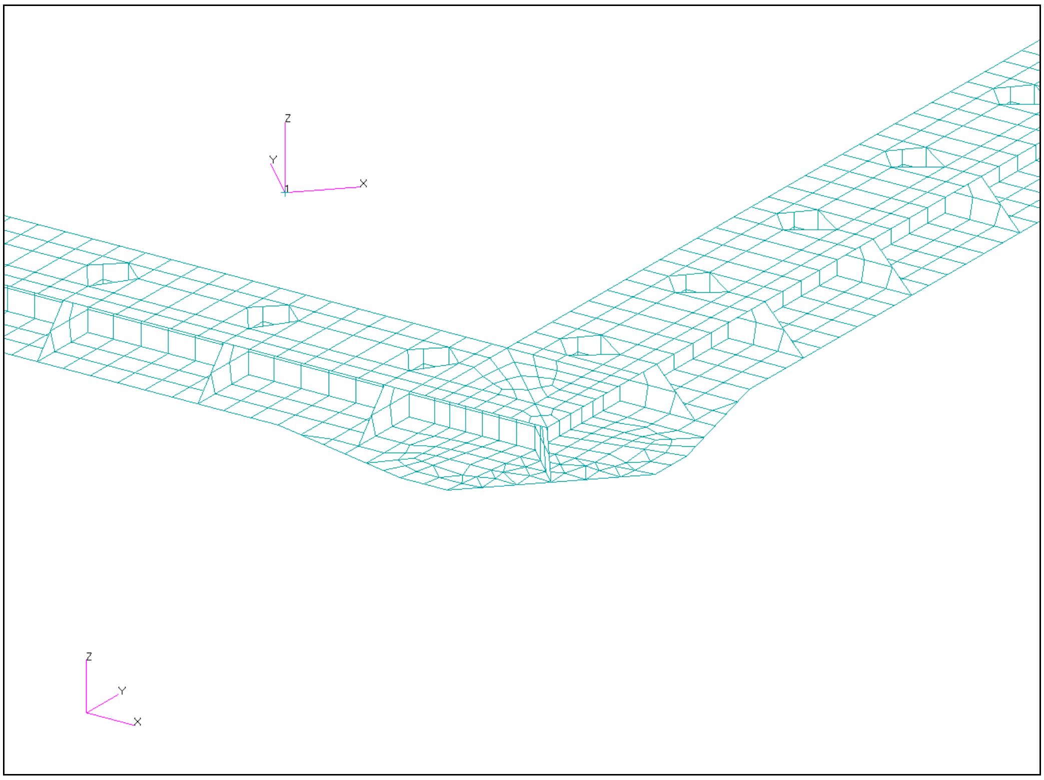


Fig 2.6 FEM Mesh in group I-Frame (local)

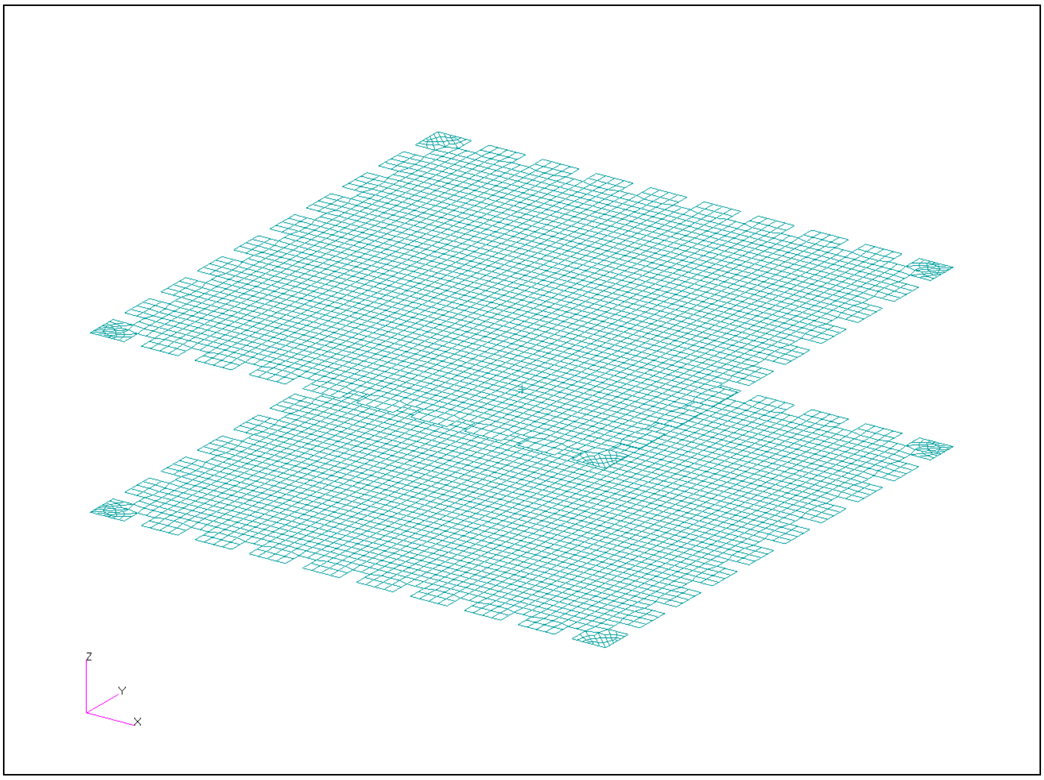


Fig 2.7 FEM Mesh in group Honey-Plate

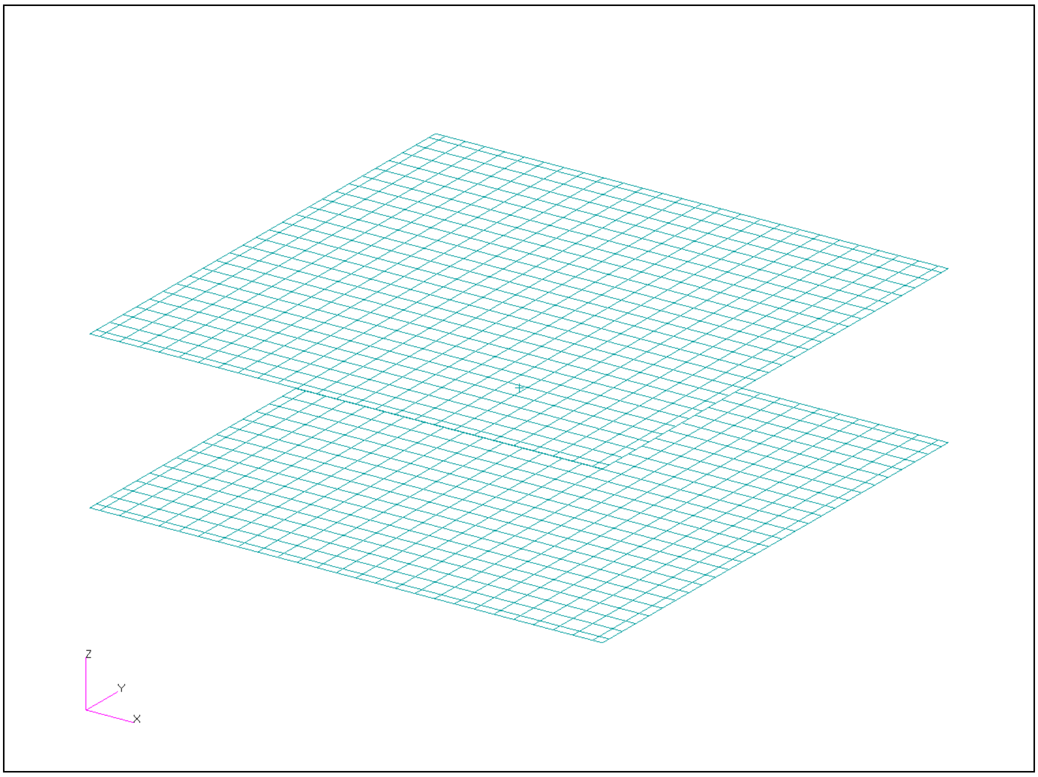


Fig 2.8 FEM Mesh in group Honey-Pad

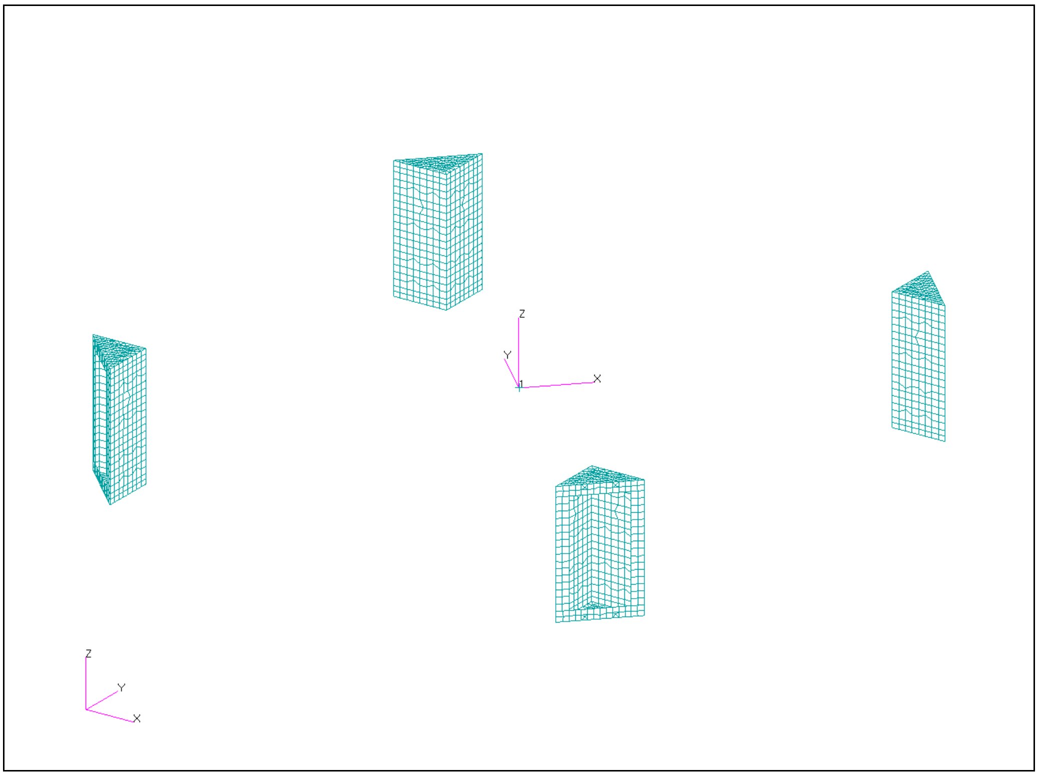


Fig 2.9 FEM Mesh in group Bracket

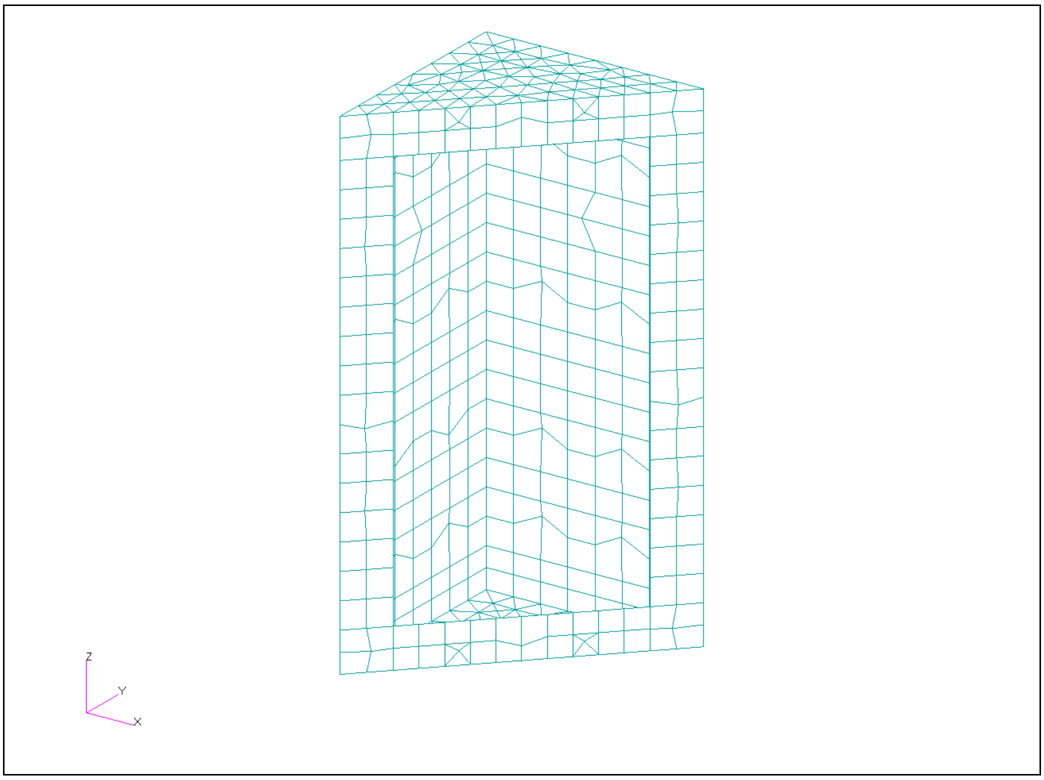


Fig 2.10 FEM Mesh in group Bracket (local)

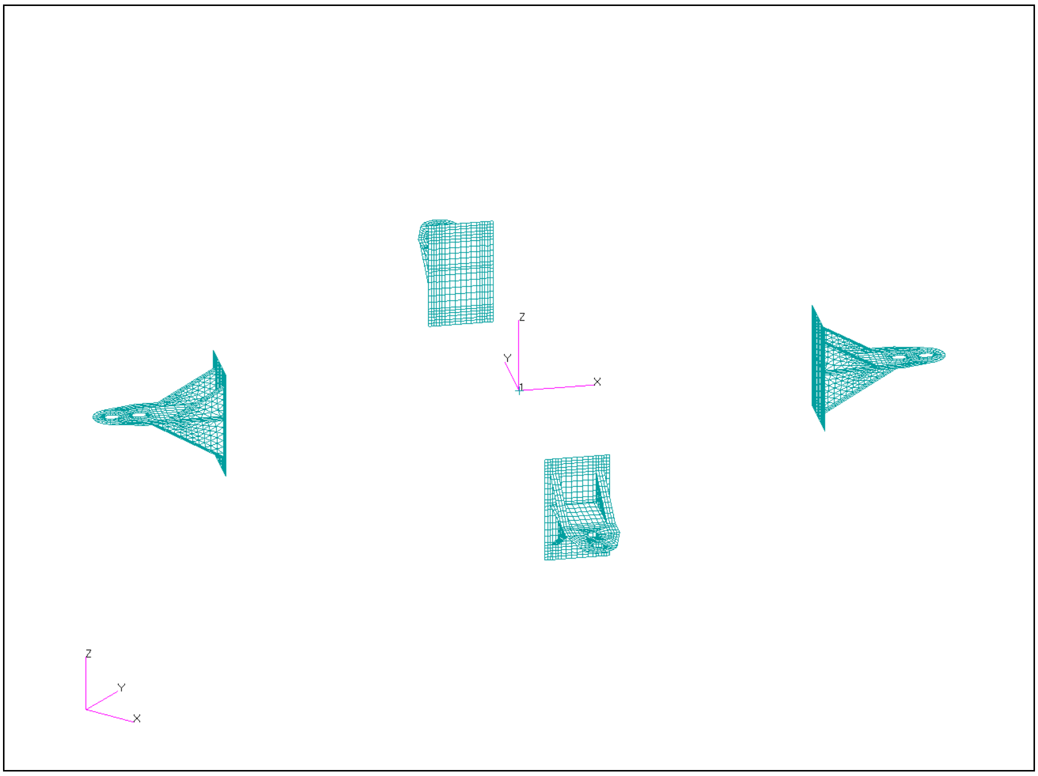


Fig 2.11 FEM Mesh in group Support

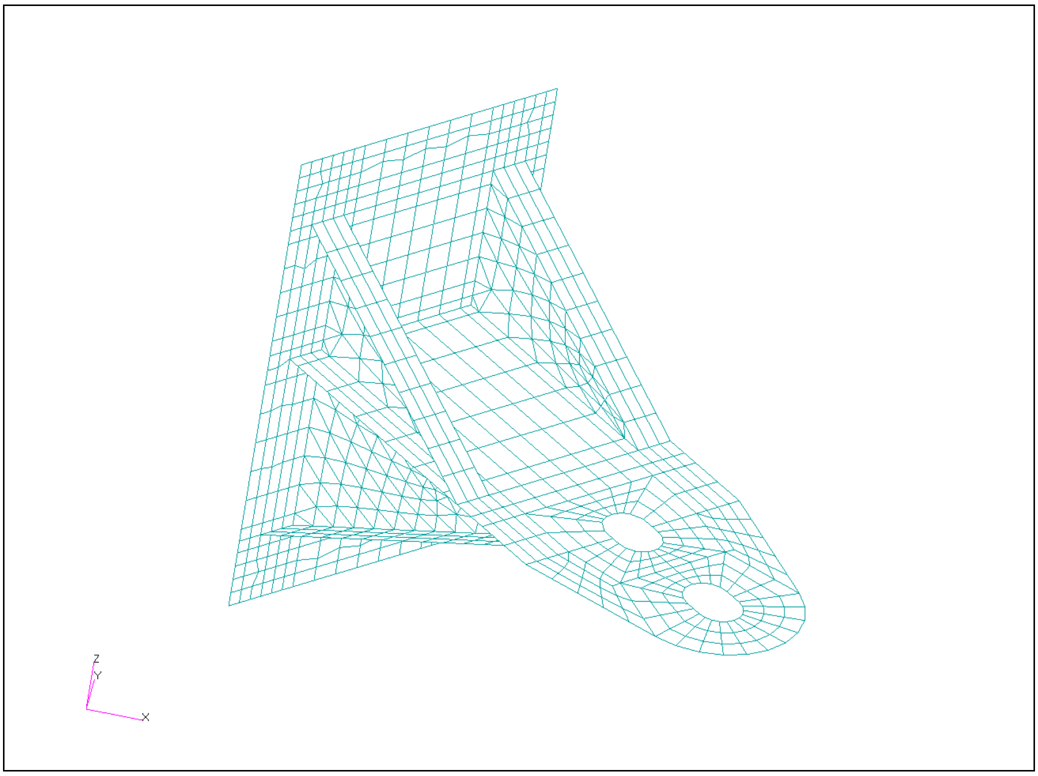


Fig 2.12 FEM Mesh in group Support (local)

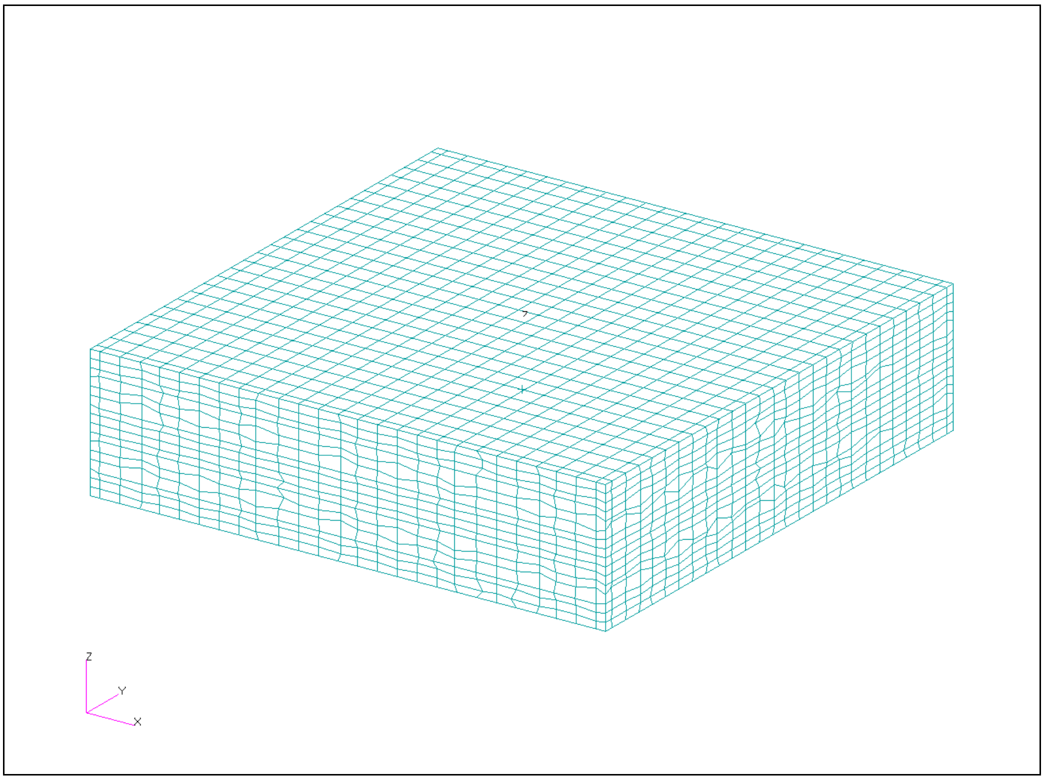


Fig 2.13 CHEXA elements in group Pancake

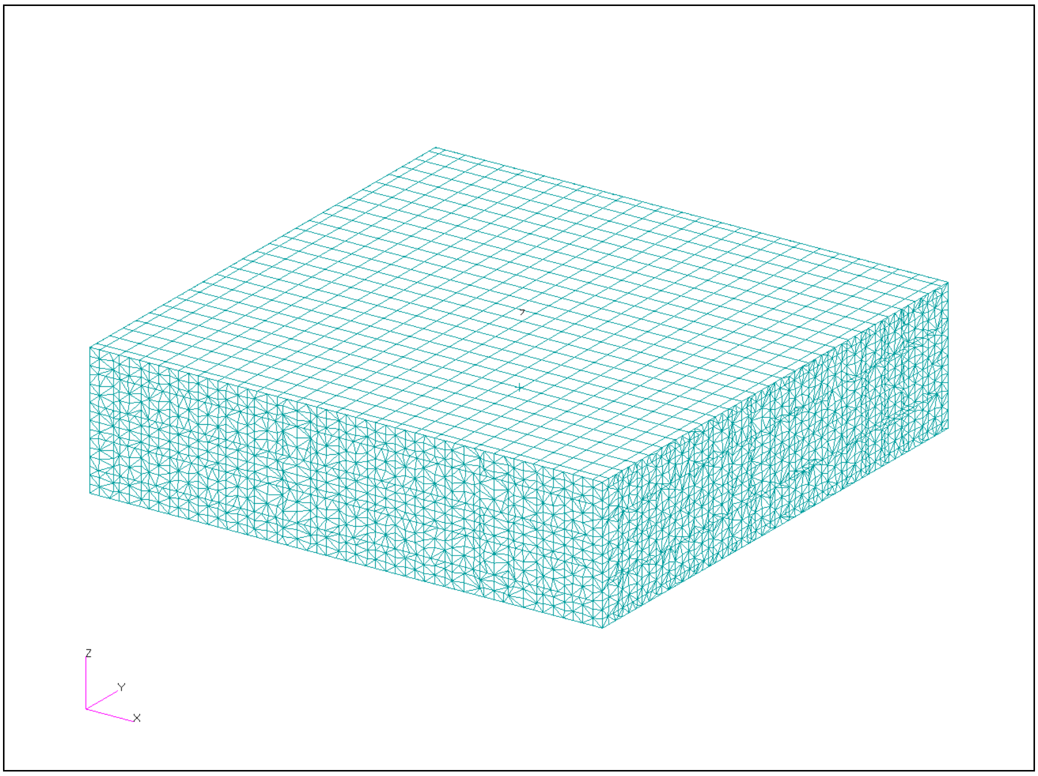


Fig 2.14 Shell elements in group Pancake

2.4 Connections between FEM components

The fasteners (bolts and shear pins) are used to assemble all components structure into the ECAL structure. So we use the beam elements (CBAR) and MPC (RBE2) of NASTRAN software to simulate their function to transfer loads. CBAR elements are used for bolts, CBAR elements with 2 DOFs of RBE2 element on one node are used for shear pins. The element forces of beam elements obtained in FEM analysis are also used for the fasteners safety margin check later.

There are springfoams between Pancake and ECAL structure. In this ECAL FEM model, CBAR Elements are also used to connect the Pancake's nodes on the 6 outside surfaces with the corresponding nodes on the ECAL Structure. To avoid the beam elements directly connect with CHEXA elements, shell elements are created enveloping on the surface of Pancake. So the Pancake and the ECAL structure are linked properly on the FEM model.

All these connections (MPCs or CBAR Elements) in the PATRAN software are shown in Table 2. The Connections in the FEM Mesh are shown in Fig. 3.1~3.9.

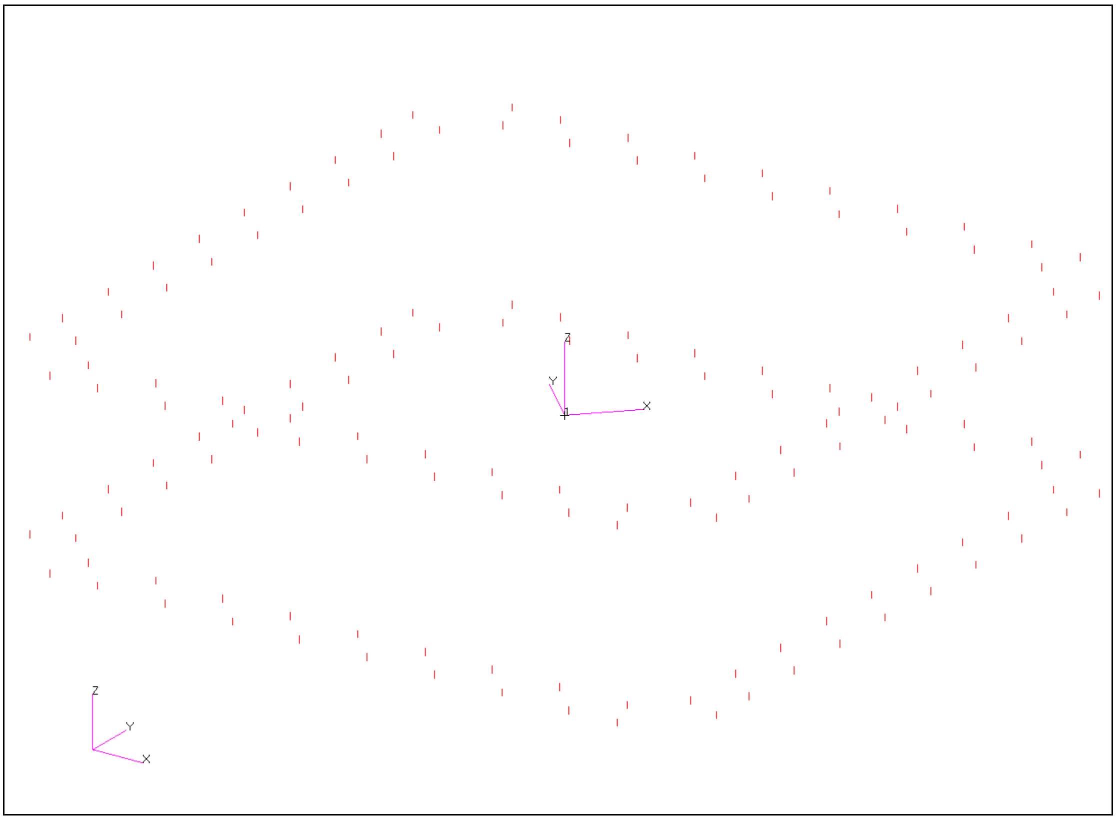


Fig 3.1 CBAR elements in group bolt-IFrame-sidepanel

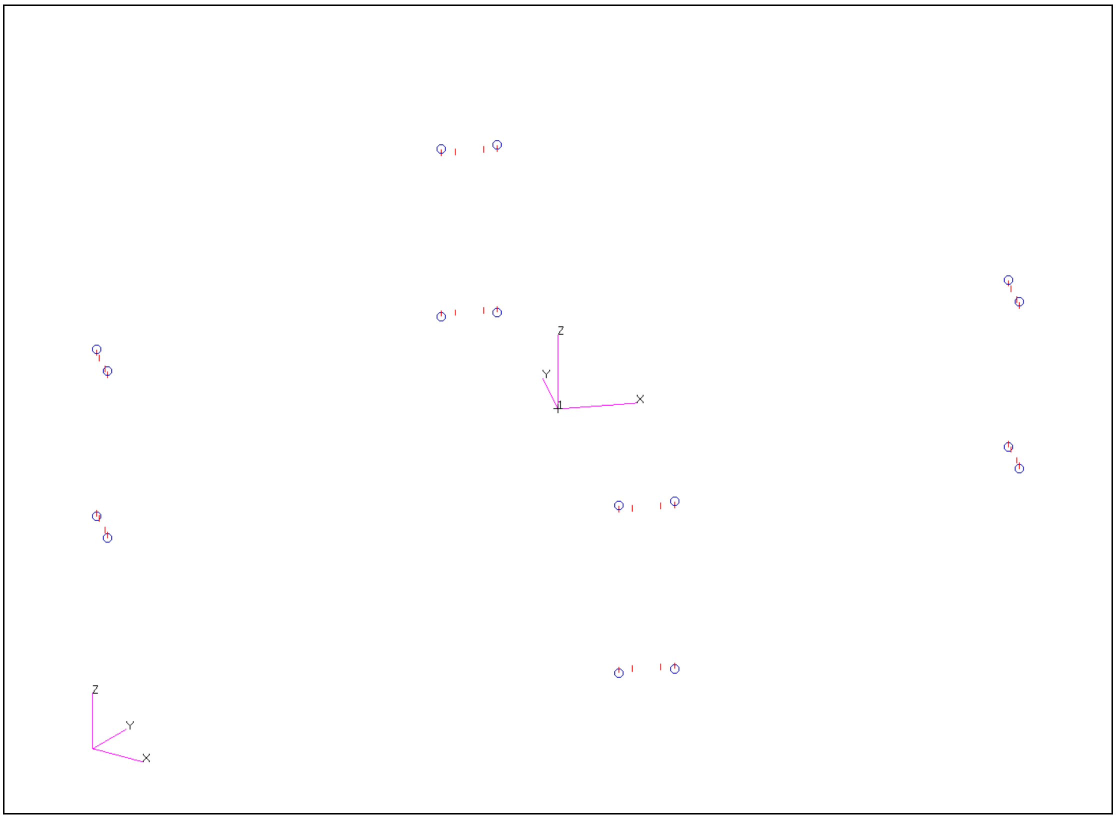


Fig 3.2 CBAR elements and MPCs in group bolt-bracket-IFrame

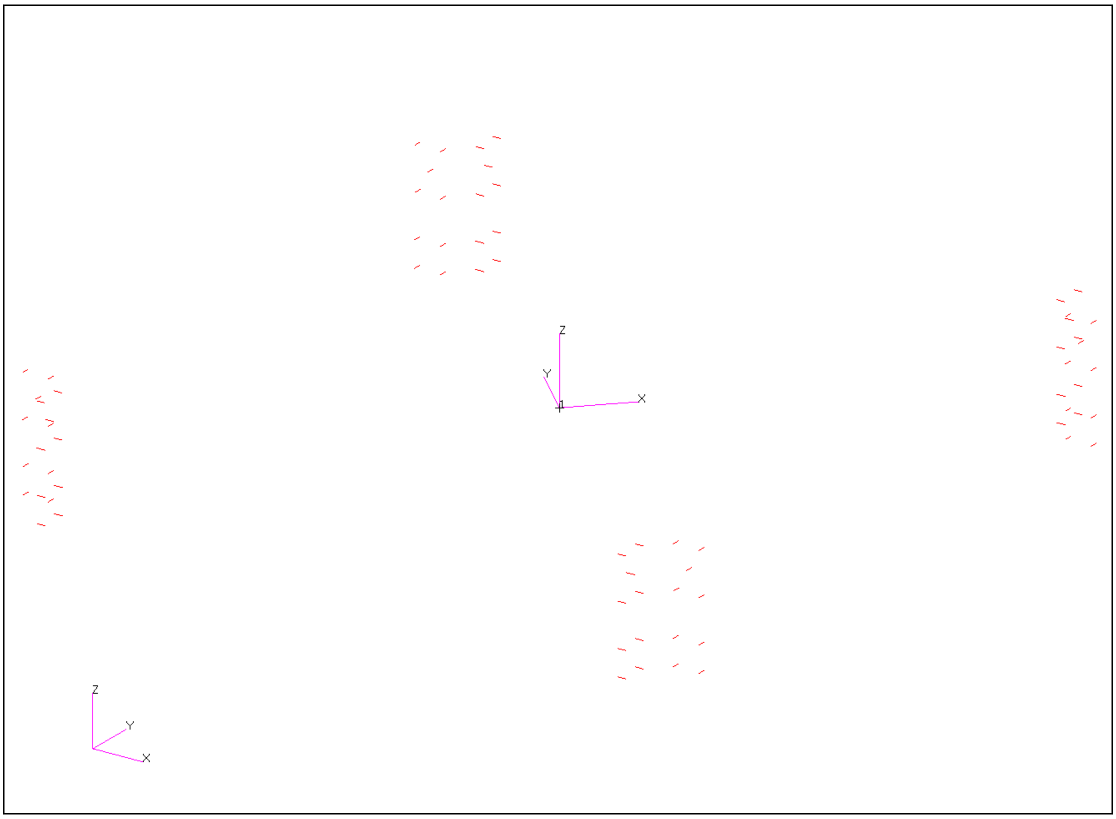


Fig 3.3 CBAR elements in group bolt-bracket-sidePanels

Fig 3.4 CBAR elements and MPCs in group bolt- bracket-support

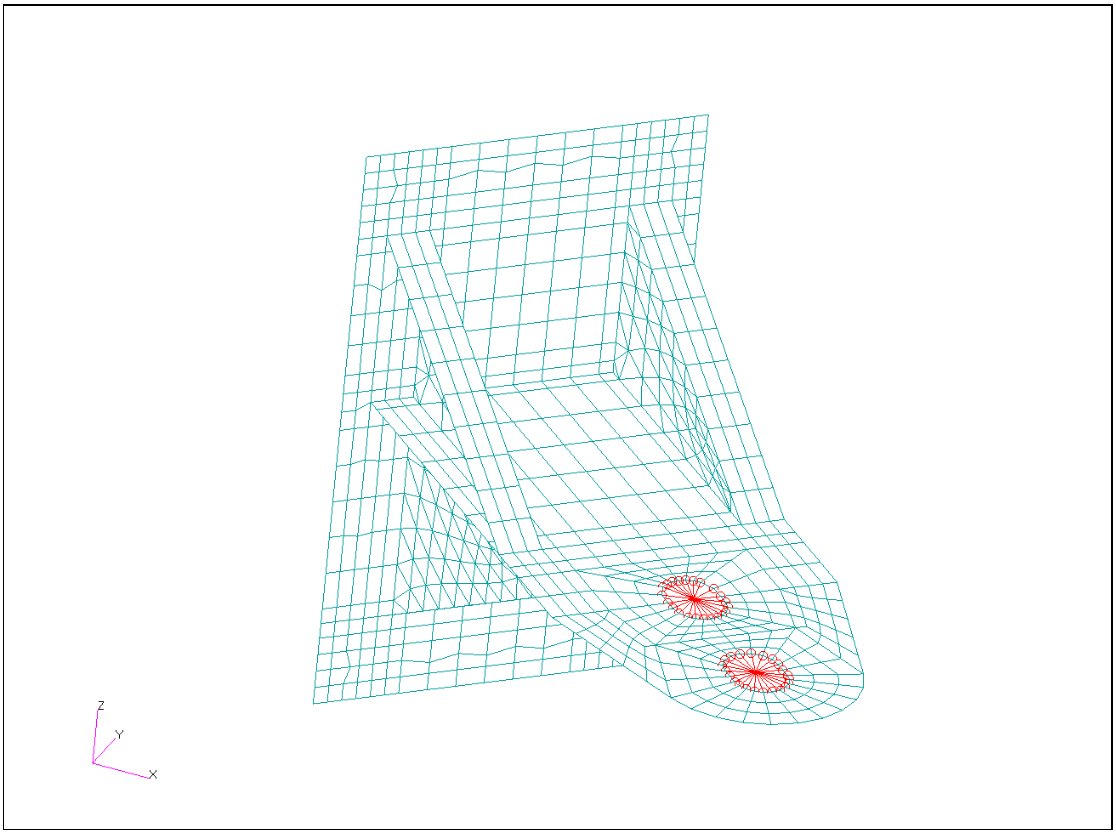


Fig 3.5 MPCs in group MPC-uss02

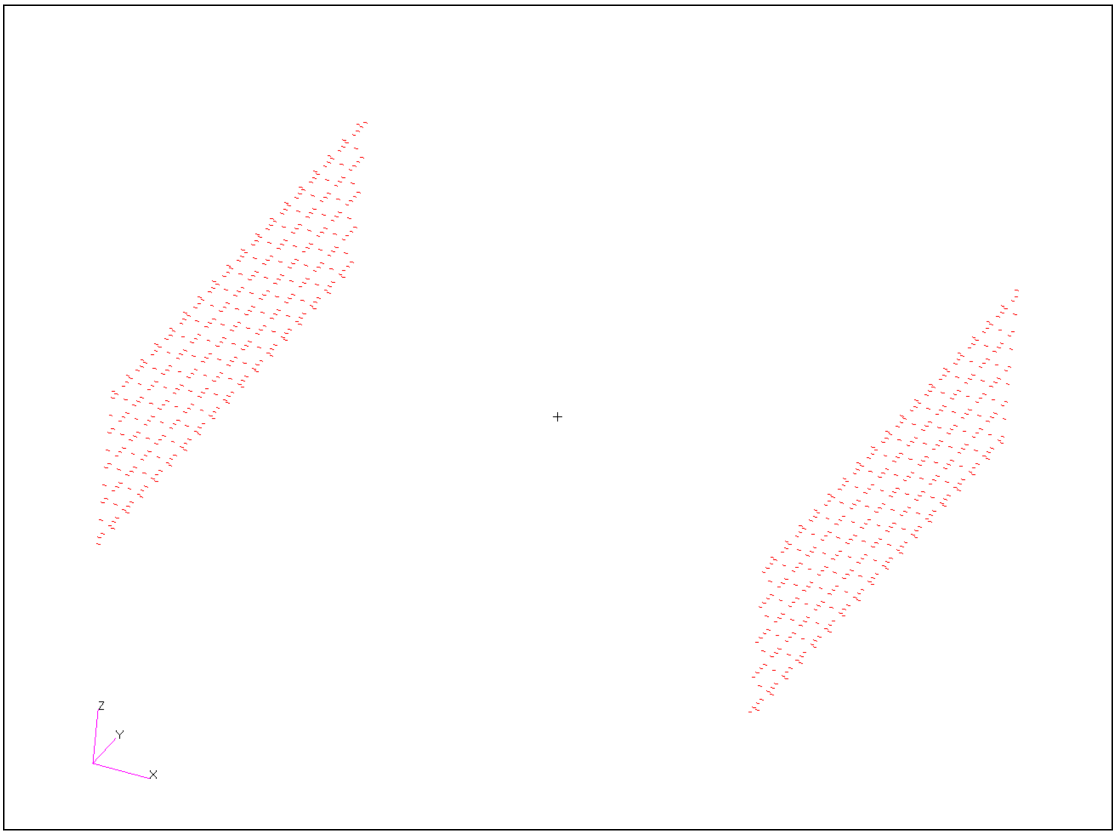


Fig 3.6 CBAR Elements in Group bar-Pancake+x and bar-Pancake-x

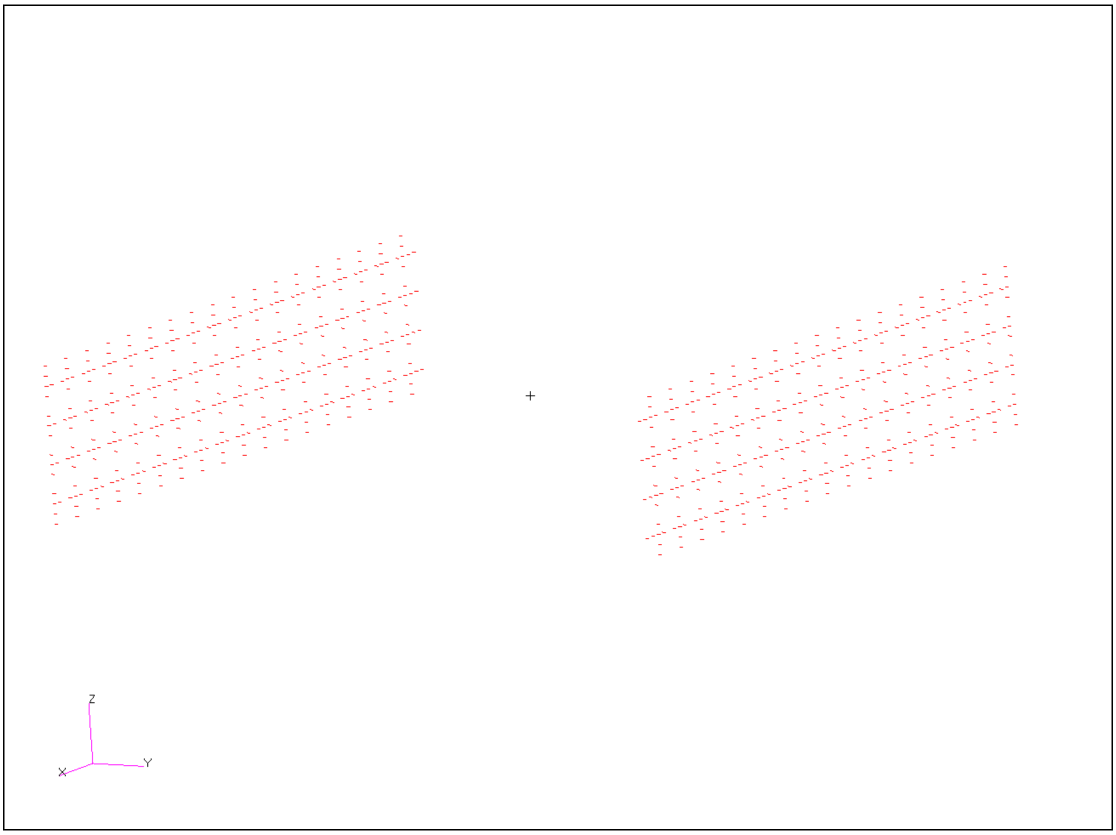


Fig 3.7 CBAR Elements in Group bar-Pancake+y and bar-Pancake-y

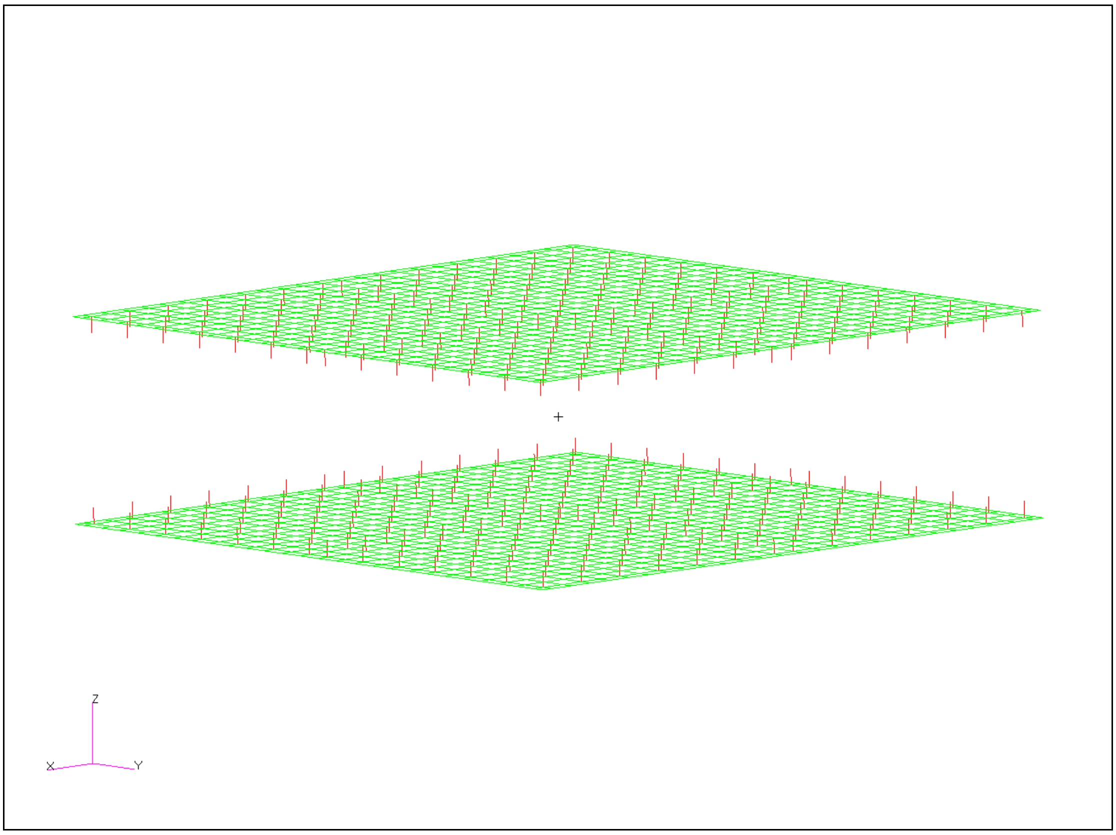


Fig 3.8 CBAR Elements in Group bar-honey-pad

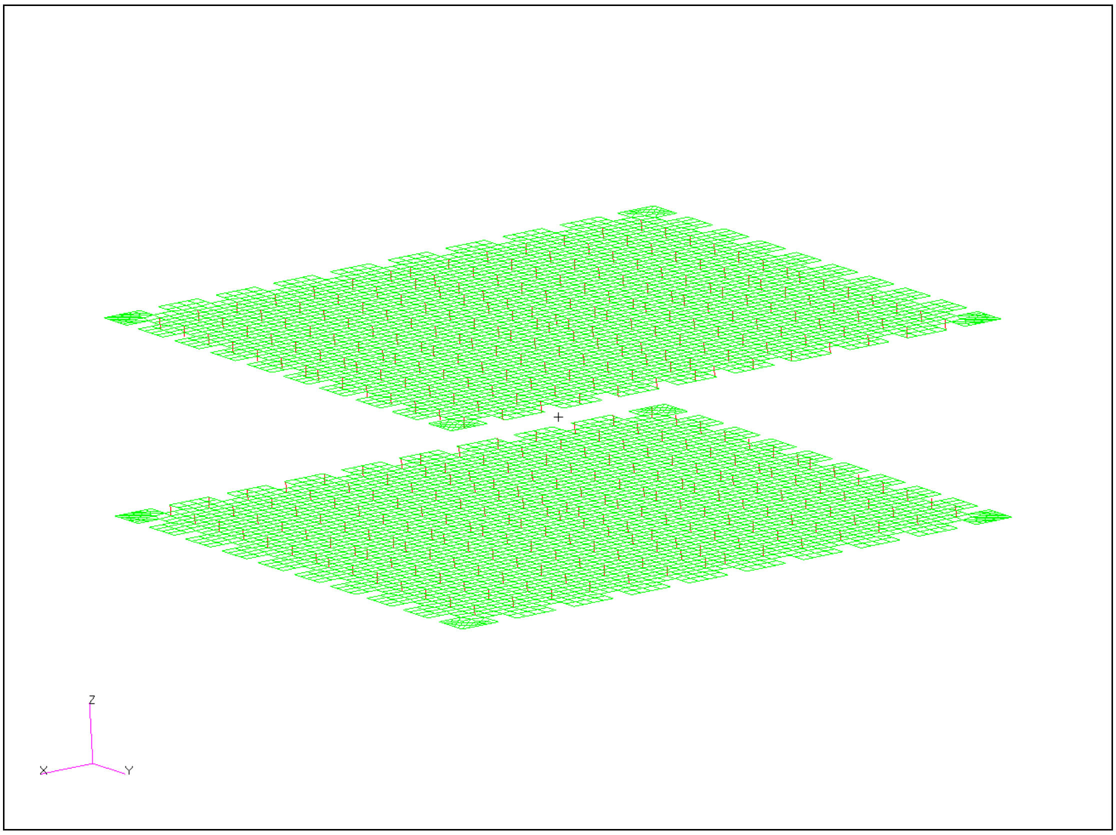


Fig 3.9 CBAR Elements in Group bar-honey-plate

2.5 Mass and Material property

1. Material Property of Aluminium:

Youngs modulus: E=6.9e10 Pa,

yielding strength Fty=290Mpa*,

ultimate strength Ftu=390Mpa.

density=2700kg/m3.

2. Material Property of Pancake:

Composite young's modulus of Pancake is E=6.3e9 Pa,

density=6749.3 kg/m3 (in order to make the total weight 500 kg),

ultimate strength Ftu=65Mpa.

3. Material Property of Honeycomb Core

Youngs modulus: E=6.98e8 Pa, density=48kg/m3.

The mass property for different groups in the ECAL FEM model are shown in Table 4:

Table 4 Mass property in ECAL FEM model

Components	Structure mass(kg)	No structure mass(kg)
Pancake	500	
Honeycomb structure (I-Frame + Honeycomb Plates+ Honeycomb Pads)	22.98	
Front-panel	12.46	40.
Left-panel	11.77	40.
Bracket + Support beam	15.15	
ECAL Structure	**62.36**	
ECAL Nostructure		**80.**
ALL ECAL WEIGHT		**642.36**

2.6 Boundary Condition

For the SQ test, the Boundary Condition is Fixed B.C (<0, 0, 0, , , >) due to the low test level (Sine-Sweep 0.25g) and the amended preload torque on the 8 interfaces bolts between uss-02 and support beams (changed from 80N.m to 200N.m).

For the Flight Load Case calculation, the Boundary Conditions is slot B.C. with one degree of freedom free along the slot direction (< , 0, 0, , , > in Coord 1).

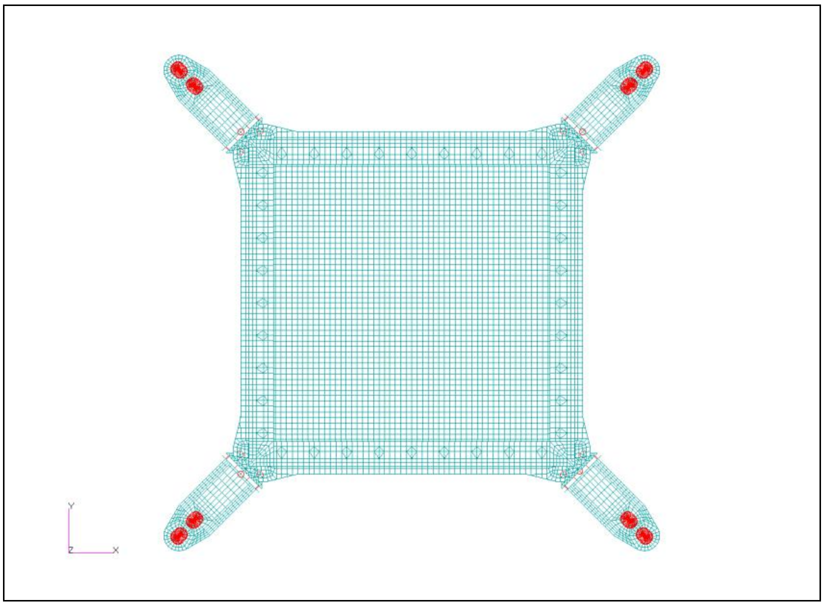


Fig 4 Boundary Condition for ECAL FEM Model

2.7 FEM Model Check

In order to make sure the ECAL FEM model is correct and mathematical consistent, Normal Mode Analysis under free-free boundary condition and fixed boundary condition are performed for model check. Including the rigid body mode check and the Stiffness Matrix K and Mass Matrix M check on the Gset, Nset, Aset level for the overall FEM model.

From the following F06 file printout it shows that Kgg, Knn, Kaa has passed the model check. The 6 free-free rigid modes are very good near Zero(10^{-4}). Good results in mathematical consistence in the ECAL FEM model are obtained here.

2.7.1 Mode check for free-free boundary condition

2.7.1.1 Model check for KGG

^^^ NO VALUE PROVIDED FOR PARAMETER CHECKTOL

^^^ CALCULATED VALUE OF CHECKTOL = 8.904017E-01

^^^ MODEL CHECKING IS INVOKED - MSC RECOMMENDS THAT A SEPARATE RUN USING PARAM,CHECKOUT,YES SHOULD ALSO BE DONE TO INSURE MODEL ACCURACY.

^^^ RESULTS OF RIGID BODY CHECKS OF MATRIX KGG FOLLOW

^^^ ALL 6 DIRECTIONS ARE CHECKED, ONLY THOSE DOFS WHICH FAIL WILL BE PRINTED

^^^**MATRIX KGG PASSED RIGID-BODY CHECKS**. THE STRAIN ENERGY IN EACH DIRECTION WAS LESS THAN 8.904017E-01

^^^RESULTS OF CHECK OF MGG

1 MSC.NASTRAN JOB CREATED ON 14-SEP-03 AT 08:49:21 SEPTEMBER 14, 2003 MSC.NASTRAN 10/31/02 PAGE 249

2.7.1.2 Model Check for KNN

^^^ RESULTS OF RIGID BODY CHECKS OF MATRIX KNN FOLLOW

^^^ ALL 6 DIRECTIONS ARE CHECKED, ONLY THOSE DOFS WHICH FAIL WILL BE PRINTED

^^^ NO VALUE PROVIDED FOR PARAMETER CHECKTOL

^^^ CALCULATED VALUE OF CHECKTOL = 1.600749E+00

^^^**MATRIX KNN PASSED RIGID-BODY CHECKS**. THE STRAIN ENERGY IN EACH DIRECTION WAS LESS THAN 1.600749E+00

2.7.1.3 Model Check for KAA

^^^ RESULTS OF RIGID BODY CHECKS OF MATRIX KAA FOLLOW

^^^ ALL 6 DIRECTIONS ARE CHECKED, ONLY THOSE DOFS WHICH FAIL WILL BE PRINTED

^^^ NO VALUE PROVIDED FOR PARAMETER CHECKTOL

^^^ CALCULATED VALUE OF CHECKTOL = 1.600749E+00

^^^**MATRIX KAA PASSED RIGID-BODY CHECKS**. THE STRAIN ENERGY IN EACH DIRECTION WAS LESS THAN 1.600749E+00

2.7.1.4 Free-free normal mode

E I G E N V A L U E A N A L Y S I S S U M M A R Y (READ MODULE)

BLOCK SIZE USED 7

NUMBER OF DECOMPOSITIONS 2

NUMBER OF ROOTS FOUND 10

NUMBER OF SOLVES REQUIRED 9

1 MSC.NASTRAN JOB CREATED ON 14-SEP-03 AT 08:49:21 SEPTEMBER 14, 2003 MSC.NASTRAN 10/31/02 PAGE 255

0 SUBCASE 1

R E A L E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	2.462040E-07	4.961895E-04	7.897101E-05	1.000000E+00	2.462040E-07
2	2	3.152569E-07	5.614774E-04	8.936190E-05	1.000000E+00	3.152569E-07
3	3	5.077854E-07	7.125906E-04	1.134123E-04	1.000000E+00	5.077854E-07
4	4	5.454970E-07	7.385777E-04	1.175483E-04	1.000000E+00	5.454970E-07
5	5	8.010380E-07	8.950073E-04	1.424448E-04	1.000000E+00	8.010380E-07
6	6	1.009460E-06	1.004719E-03	1.599059E-04	1.000000E+00	1.009460E-06
7	7	1.040215E+06	1.019909E+03	1.623236E+02	1.000000E+00	1.040215E+06
8	8	1.568706E+06	1.252480E+03	1.993384E+02	1.000000E+00	1.568706E+06
9	9	1.869907E+06	1.367445E+03	2.176357E+02	1.000000E+00	1.869907E+06
10	10	1.894450E+06	1.376390E+03	2.190593E+02	1.000000E+00	1.894450E+06

2.7.2 Mode check for fixed boundary condition

Because the model check results in KGG, KNN for fixed boundary condition are as same as that for free-free boundary conditions. So only the results in MGG, MNN, MAA, and KAA for fixed conditions are listed here.

2.7.2.1 Model check for MGG

```
0        MATRIX WGHTG     (GINO NAME 101 ) IS A DB   PREC               6 COLUMN X              6 ROW SQUARE     MATRIX.
0COLUMN        1        ROWS        1 THRU        6        --------------------------------------------------
     ROW          1)     6.4348D+02   0.0000D+00   0.0000D+00   0.0000D+00   3.9757D-02   1.5633D-04
0COLUMN        2        ROWS        2 THRU        6        --------------------------------------------------
     ROW          2)     6.4348D+02   0.0000D+00 -3.9757D-02   0.0000D+00 -1.7769D-07
0COLUMN        3        ROWS        3 THRU        5        --------------------------------------------------
     ROW          3)     6.4348D+02 -1.5633D-04   1.7769D-07
0COLUMN        4        ROWS        2 THRU        6        --------------------------------------------------
     ROW          2)    -3.9757D-02 -1.5633D-04   3.2991D+01   8.5774D-03   1.7052D-08
0COLUMN        5        ROWS        1 THRU        6        --------------------------------------------------
     ROW          1)     3.9757D-02   0.0000D+00   1.7769D-07   8.5774D-03   3.3042D+01   4.8086D-08
0COLUMN        6        ROWS        1 THRU        6        --------------------------------------------------
     ROW          1)     1.5633D-04 -1.7769D-07   0.0000D+00   1.7052D-08   4.8086D-08   6.2196D+01
0THE NUMBER OF NON-ZERO TERMS IN THE DENSEST COLUMN =          5
0THE DENSITY OF THIS MATRIX IS   66.67 PERCENT.
```

2.7.2.2 Model check for MNN

```
0        MATRIX WGHTN     (GINO NAME 101 ) IS A DB   PREC               6 COLUMN X              6 ROW SQUARE     MATRIX.
0COLUMN        1        ROWS        1 THRU        6        --------------------------------------------------
     ROW          1)     6.4348D+02   0.0000D+00   0.0000D+00   0.0000D+00   3.9757D-02   1.5633D-04
0COLUMN        2        ROWS        2 THRU        6        --------------------------------------------------
     ROW          2)     6.4348D+02   0.0000D+00 -3.9757D-02   0.0000D+00 -1.7769D-07
```

```
0COLUMN    3    ROWS    3 THRU    5    --------------------------------------------------
     ROW    3)    6.4348D+02 -1.5633D-04  1.7769D-07
0COLUMN    4    ROWS    1 THRU    6    --------------------------------------------------
     ROW    1)   -2.7105D-20 -3.9757D-02 -1.5633D-04  3.2991D+01  8.5774D-03  1.7052D-08
0COLUMN    5    ROWS    1 THRU    6    --------------------------------------------------
     ROW    1)    3.9757D-02  2.7105D-20  1.7769D-07  8.5774D-03  3.3042D+01  4.8086D-08
0COLUMN    6    ROWS    1 THRU    6    --------------------------------------------------
     ROW    1)    1.5633D-04 -1.7769D-07  0.0000D+00  1.7052D-08  4.8086D-08  6.2196D+01
```

2.7.2.3 Model check for MNN

```
^^^ RESULTS OF RIGID BODY CHECKS OF MATRIX KAA FOLLOW
^^^ ALL 6 DIRECTIONS ARE CHECKED, ONLY THOSE DOFS WHICH FAIL WILL BE PRINTED
^^^ NO VALUE PROVIDED FOR PARAMETER CHECKTOL
^^^ CALCULATED VALUE OF CHECKTOL =    8.904017E-01
^^^LARGEST STRAIN ENERGY OF   1.241307E+11 EXCEEDS PROVIDED LIMIT OF     8.904017E-01
^^^ IF THE G- OR N- CHECKS HAVE FAILED, THEY    SHOULD BE RESOLVED BEFORE LOOKING AT THE A- SET CHECKS
^^^ THE FOLLOWING DIRECTIONS HAVE FAILED THE TEST
^^^DIRECTION            1 HAS STRAIN ENERGY = =    1.241306E+11
^^^DIRECTION            2 HAS STRAIN ENERGY = =    1.241307E+11
^^^DIRECTION            3 HAS STRAIN ENERGY = =    5.227160E+10
^^^DIRECTION            4 HAS STRAIN ENERGY = =    1.402759E+10
^^^DIRECTION            5 HAS STRAIN ENERGY = =    1.402759E+10
^^^DIRECTION            6 HAS STRAIN ENERGY = =    6.699359E+10
^^^       ^^^PASS=            -1 CHECKDR=            -1QUITDR=          -1
```

2.7.2.4 Model check for MAA

```
0         MATRIX WGHTA      (GINO NAME 101 ) IS A DB   PREC              6 COLUMN X              6 ROW SQUARE     MATRIX.
0COLUMN        1        ROWS        1 THRU        6        --------------------------------------------------
     ROW         1)      6.4335D+02   0.0000D+00   0.0000D+00   0.0000D+00   3.8611D-02   1.5636D-04
0COLUMN        2        ROWS        2 THRU        6        --------------------------------------------------
     ROW         2)      6.4335D+02   0.0000D+00 -3.8611D-02   0.0000D+00 -2.0931D-07
0COLUMN        3        ROWS        3 THRU        5        --------------------------------------------------
     ROW         3)      6.4335D+02 -1.5636D-04   2.0931D-07
0COLUMN        4        ROWS        1 THRU        6        --------------------------------------------------
     ROW         1)     -2.7105D-20 -3.8611D-02 -1.5636D-04   3.2957D+01   8.5773D-03   1.7337D-08
0COLUMN        5        ROWS        1 THRU        6        --------------------------------------------------
     ROW         1)      3.8611D-02   2.7105D-20   2.0931D-07   8.5773D-03   3.3008D+01   4.8381D-08
0COLUMN        6        ROWS        1 THRU        6        --------------------------------------------------
     ROW         1)      1.5636D-04 -2.0931D-07   0.0000D+00   1.7337D-08   4.8381D-08   6.2127D+01
```

```
                    E I G E N V A L U E   A N A L Y S I S   S U M M A R Y   (READ MODULE)
                              BLOCK SIZE USED ......................     7
                              NUMBER OF DECOMPOSITIONS ............      2
                              NUMBER OF ROOTS FOUND ................    10
                              NUMBER OF SOLVES REQUIRED ...........     10
```

R E A L   E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	1.497070E+05	3.869199E+02	6.158021E+01	1.000000E+00	1.497070E+05

2	2	2.665951E+05	5.163284E+02	8.217622E+01	1.000000E+00	2.665951E+05
3	3	2.680720E+05	5.177567E+02	8.240353E+01	1.000000E+00	2.680720E+05
4	4	3.613627E+05	6.011345E+02	9.567352E+01	1.000000E+00	3.613627E+05
5	5	3.641919E+05	6.034832E+02	9.604733E+01	1.000000E+00	3.641919E+05
6	6	3.677788E+05	6.064477E+02	9.651914E+01	1.000000E+00	3.677788E+05
7	7	1.937717E+06	1.392019E+03	2.215467E+02	1.000000E+00	1.937717E+06
8	8	2.800058E+06	1.673337E+03	2.663199E+02	1.000000E+00	2.800058E+06
9	9	3.446240E+06	1.856405E+03	2.954560E+02	1.000000E+00	3.446240E+06
10	10	3.921003E+06	1.980152E+03	3.151510E+02	1.000000E+00	3.921003E+06

3 Space Qualification Test

The Space Qualification test was done in Beiing Institute of Satellite Environment Engineering(BISEE) on Juanary 2003. There were three kinds of tests performed for the ECAL structure: the Sine-sweep test, the Random test, and the Sine-Burst test for X, Y, Z direction separately as shown in Fig. 5.1~5.2.

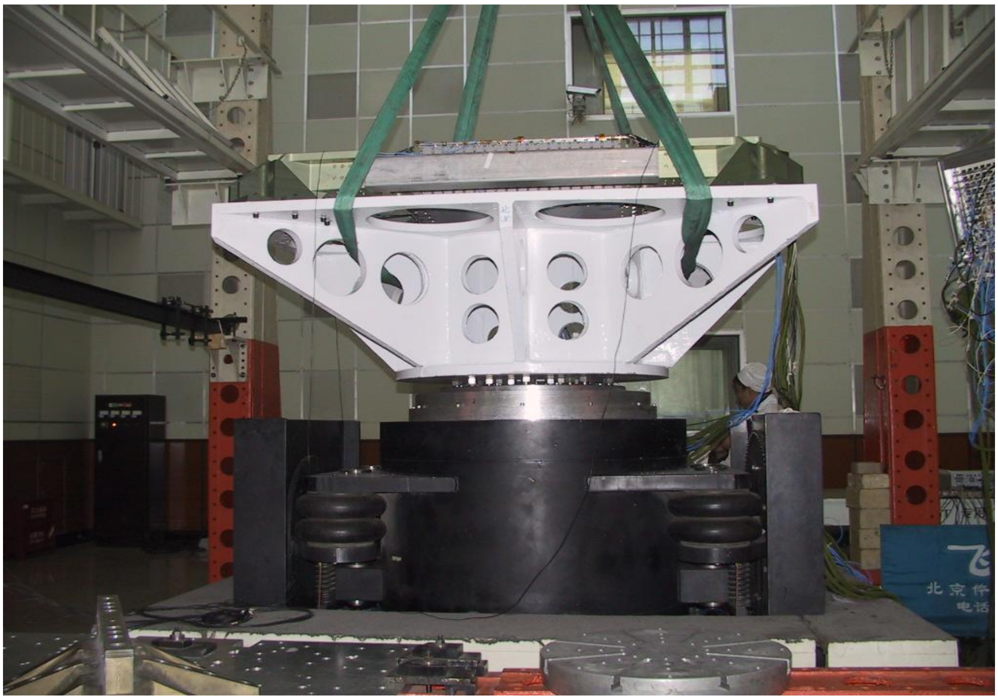


Fig 5.1 ECAL test configuration in Z direction

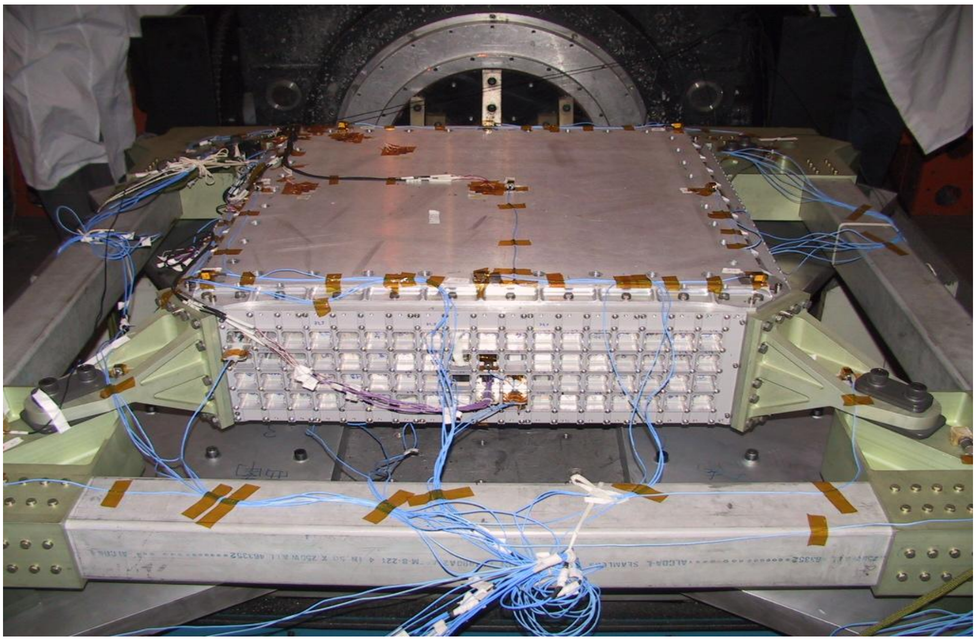


Fig 5.2 ECAL test configuration in X and Y direction

In order to do the FEM model correlation, the information of the natural frequencies from sine-sweep test and the stresses from Sine-Burst test are used here.

3.1 Measurement Points

There are 36 accelerometers (92 channels) and 16 strain gauges (48 channels) in the test. These points are shown in figure 6.

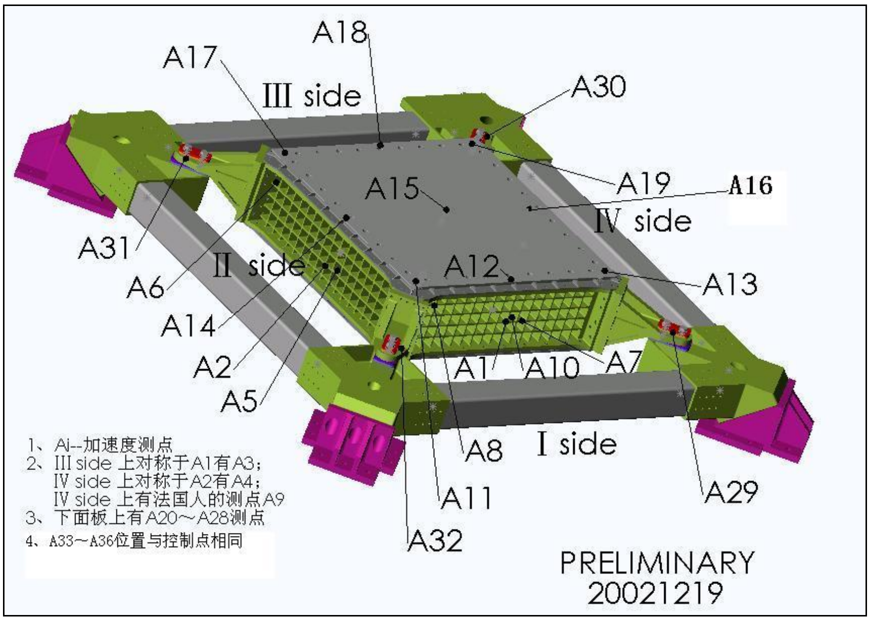


Fig6.1 Measurement points for Acceleration A1-A32

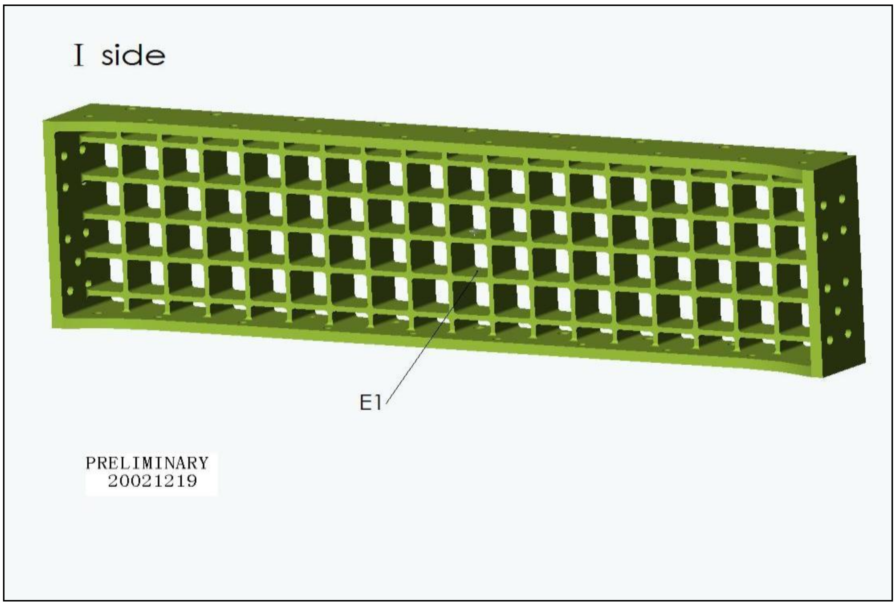


Fig6.2 Measurement points for Strain E1

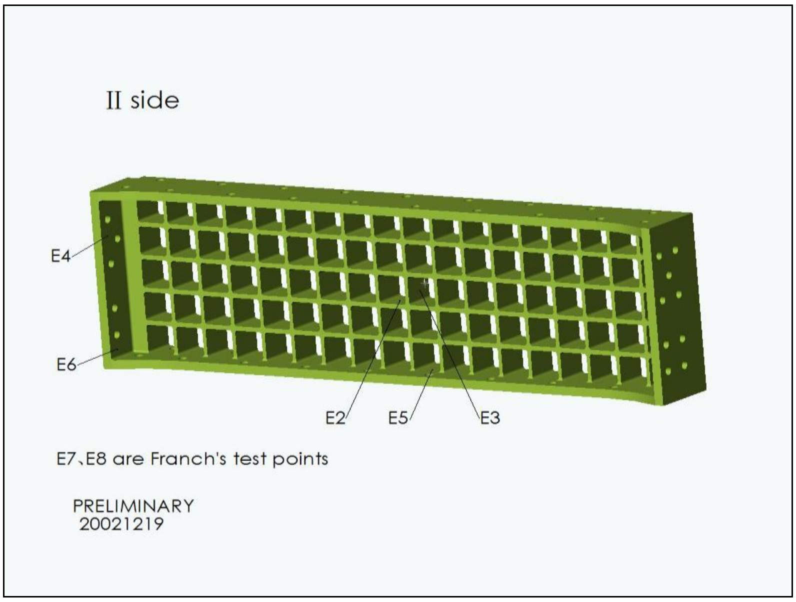


Fig6.3 Measurement points for Strain E2-E6 (E7-E8 in PMTs)

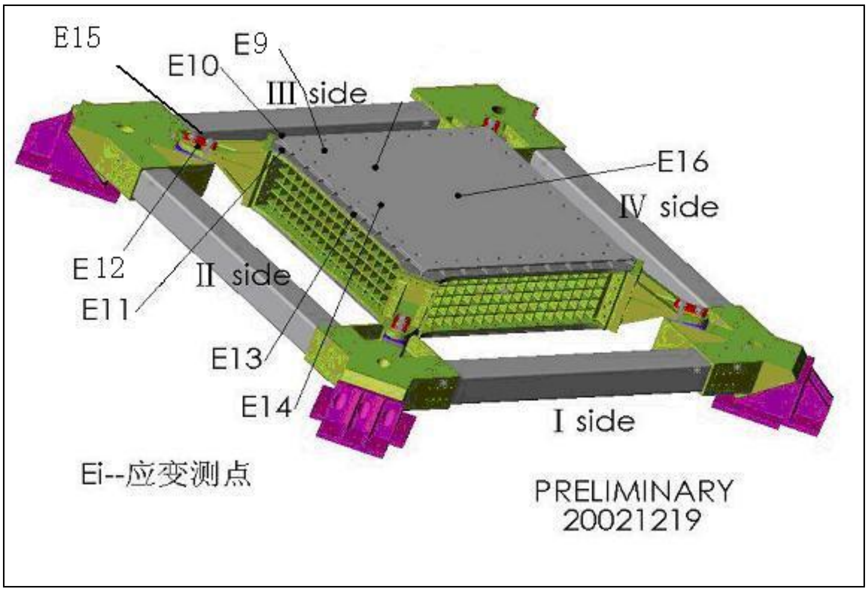


Fig6.4 Measurement points for Strain E9-E16

3.2 Sine-Sweep Test results

The typical sine-sweep response curves are shown in Fig. 7 for X, Y, and Z direction separately. From the results we can see that the first natural frequency of ECAL is 65Hz along Z direction, 86.8 Hz along X direction, and 87.6 Hz along Y direction.

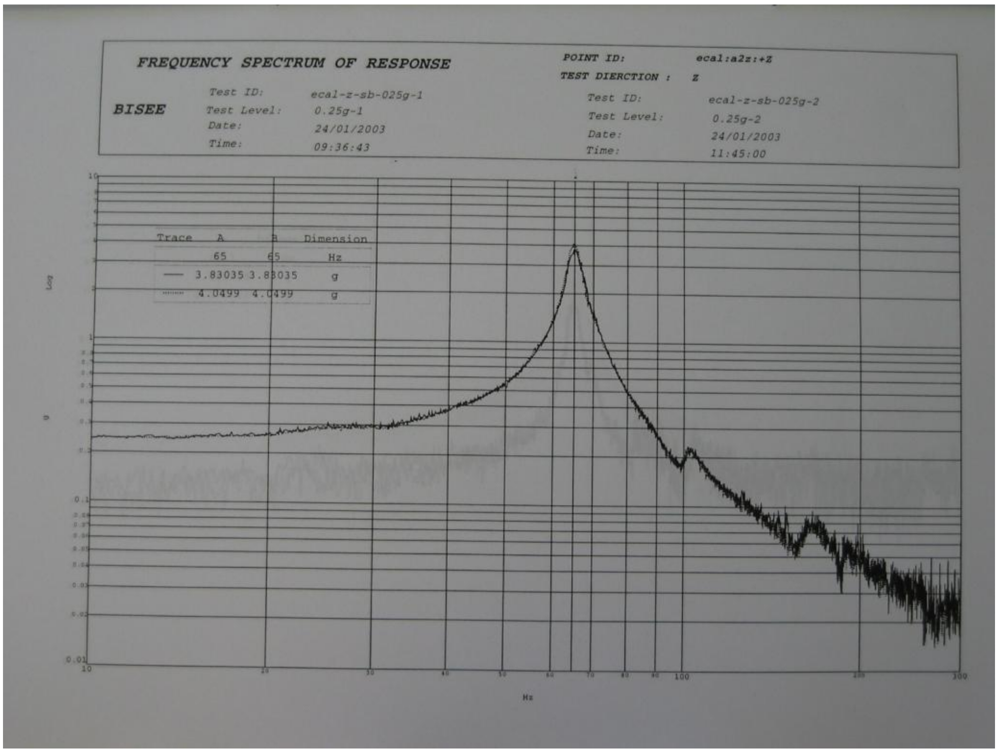
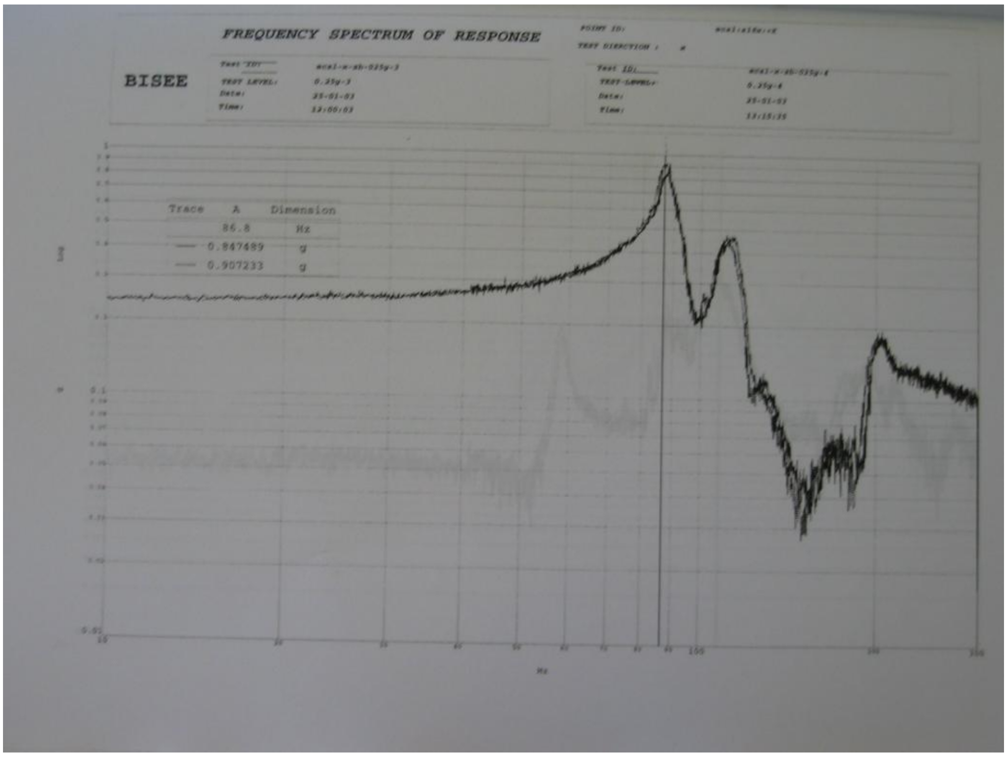
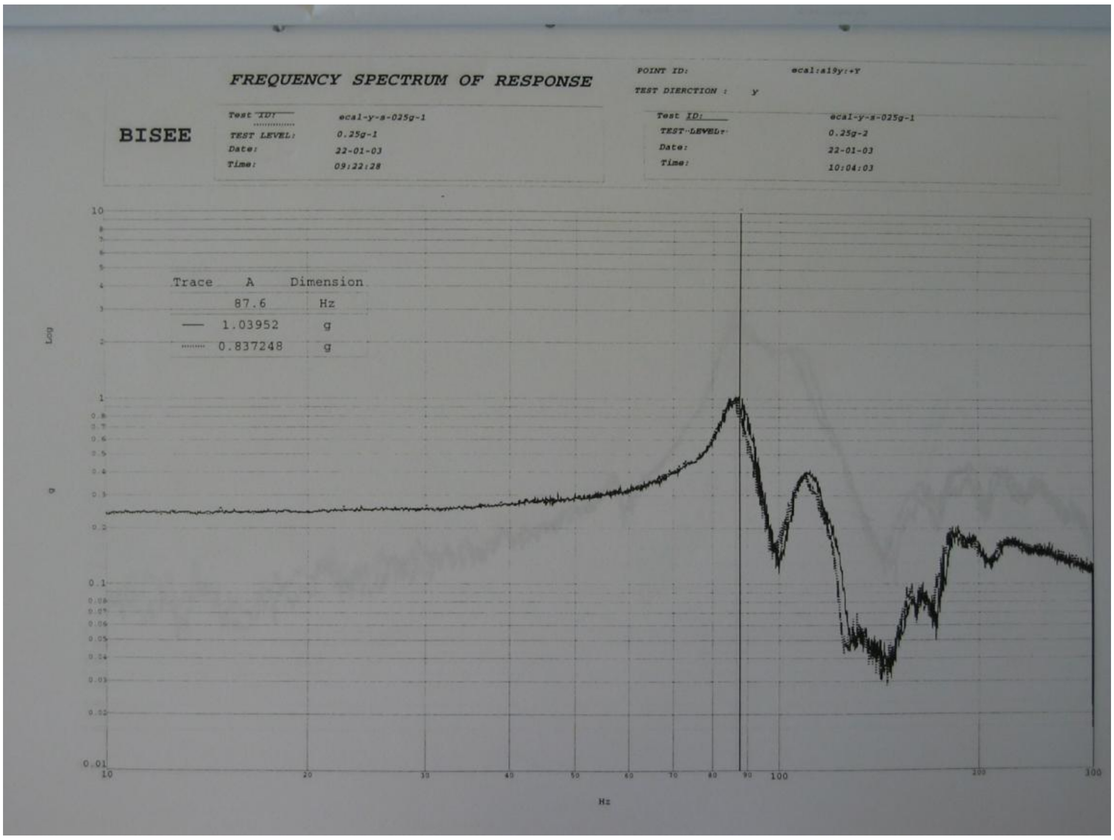


Fig 7.1 Typical curve of Sine-Sweep in Z direction (peak 65Hz)



7.2 Typical curve of Sine-Sweep in X direction (peak 86.8Hz)



7.23 Typical curve of Sine-Sweep in Y direction (peak 87.6Hz)

3.3 Sine-Burst Test results

There are 3 channels in each strain sensor points (in 0º, 45º, and 90º direction).

The strain gauges data $\varepsilon_0, \varepsilon_{45}, \varepsilon_{90}$ are converted into Max. Principal stresses by the following formula:

$$\sigma_{1,2} = \frac{E}{2}[\frac{\varepsilon_0 + \varepsilon_{90}}{1-\mu} \pm \frac{\sqrt{(\varepsilon_0 - \varepsilon_{90})^2 + (2\varepsilon_{45} - \varepsilon_0 - \varepsilon_{90})^2}}{1+\mu}]$$

The tested strain data are listed in Table 9, and converted stress listed in Table 10.

Table 9 Tested strain data

	Sine burst in X direction			Sine burst in Y direction			Sine burst in Z direction		
Measure Point	ε_0 (10^{-6})	ε_{45} (10^{-6})	ε_{90} (10^{-6})	ε_0 (10^{-6})	ε_{45} (10^{-6})	ε_{90} (10^{-6})	ε_0 (10^{-6})	ε_{45} (10^{-6})	ε_{90} (10^{-6})
1	10.8	31	11.25	11	16	7	7	45	18
2	16.3	4	9.9	41	6.7	11.9	14	7	9.7
3	16	1.9	32	9.8	4.5	17.4	20	5	13
4	10	0.8	11	7.2	0.5	20.8	23	0	36
5	60	3.8	7	31.6	5	6.8	10	9.2	17.4
6	22	86	254	9.95	25	37.5	14	145	13
7	3	18.9	16.5	33.5	179.6	62.7	4.5	11.8	6
8	6.7	4.6	5.6	20.5	62.3	55.3	4	14.3	3.6
9	38	26	31	9.98	10.6	13.4	148	67	161
10	160	161	15	188	230	0	77	187	77
11	229	60	336	41.2	34.9	66.8	130	56	109
12	100	127	77	73.9	98.8	12.8	33	33.8	5.6
13	18	2.6	15	32.5	6.48	23.4	146	36	47
14	26	37	356	59.6	89.1	23.2	255	78	157
15	61	27	50	82.4	49.8	64.6	76	29	11.3
16	15	21	22	19.4	17.14	16.5	113	106	105

Table 10 Max. Principal stress calculated from test data

Measure Point	In X direction (MPa)	In Y direction (MPa)	In Z direction (MPa)
1	2.84	1.72	3.71
2	1.34	3.51	1.24
3	2.19	1.29	1.65
4	0.93	1.32	2.61
5	5.21	2.78	1.38
6	16.3	2.90	13.0
7	1.62	15.2	1.04
8	0.62	5.49	1.32
9	3.53	1.20	14.4
10	23.9	32.2	17.4
11	25.7	5.36	11.5
12	13.4	12.7	10.4

13	1.52	2.68	12.9
14	20.6	10.3	21.4
15	5.37	7.49	6.28
16	2.07	1.94	11.3

4 MODE CORRELATIONS

Model Correlation are focused on optimizing the component modeling and adjusting Bar properties of spring foam in order to match the Sine-Sweep test data.

The Normal modes of ECAL on USS-02 are listed in Table 7. The mode shapes are shown in Fig. 5.

Table 7 Normal Mode of ECAL on USS-02

Mode No	Modes by Sine-Sweep test	FEM results after correlation	Error
1	F1=65 Hz (Z direction)	F1=61.58Hz (Z direction)	5.26%
2	F2=86.8 Hz (X direction)	F3=82.4Hz (X direction)	5.07%
2	F3=87.6 Hz (Y direction)	F2=82.2Hz (Y direction)	6.16%

Table 8 Effective Mode Mass Fraction by FEM

	T1	T2	T3	R1	R2	R3
F1	4.13E-04	4.44E-04	9.99E-01	2.26E-04	2.52E-04	-1.37E-07
F2	2.41E-01	7.33E-01	2.66E-02	-2.13E-03	7.79E-04	5.47E-05
F3	7.29E-01	2.42E-01	2.86E-02	-7.08E-04	2.31E-03	-1.16E-05

From Table 7 and 8 we can see that the first 3 modes are in good agreement in the natural frequencies and mode direction between the correlated FEM model and the test results. The mode shape are shown in Fig.8.

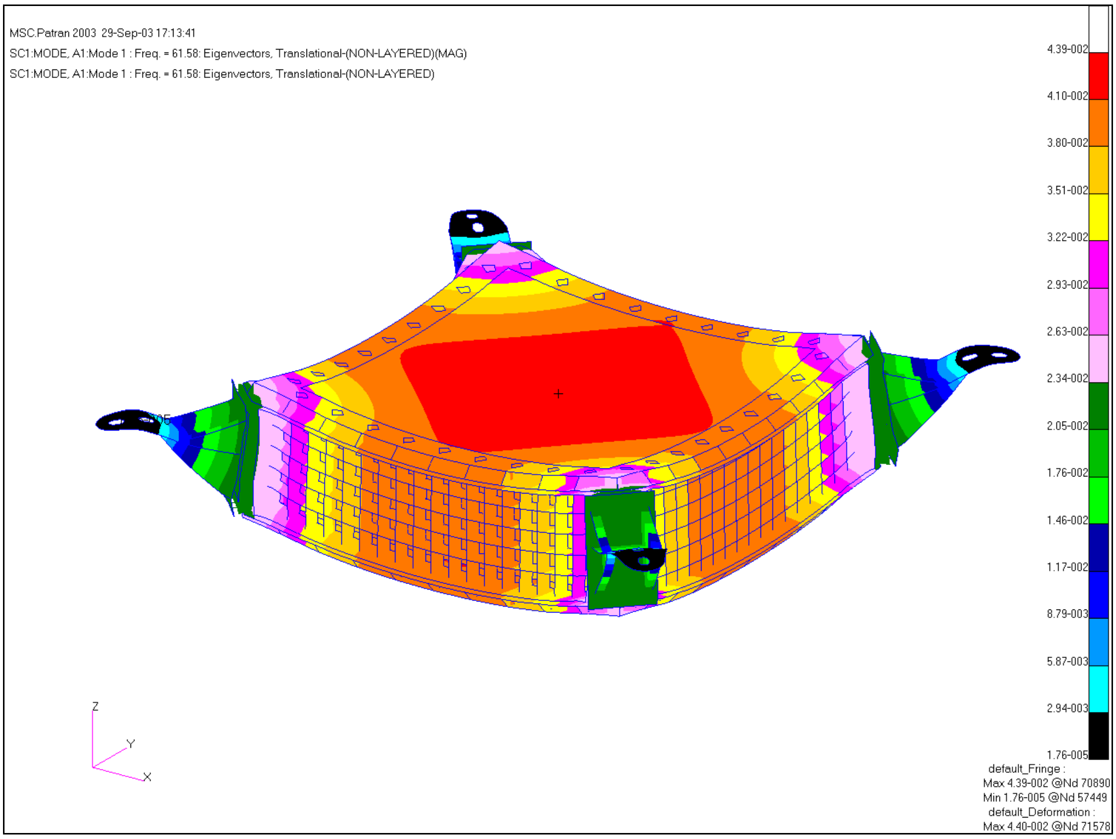


Fig 8.1 Mode shape of ECAL for f1=61.58 Hz

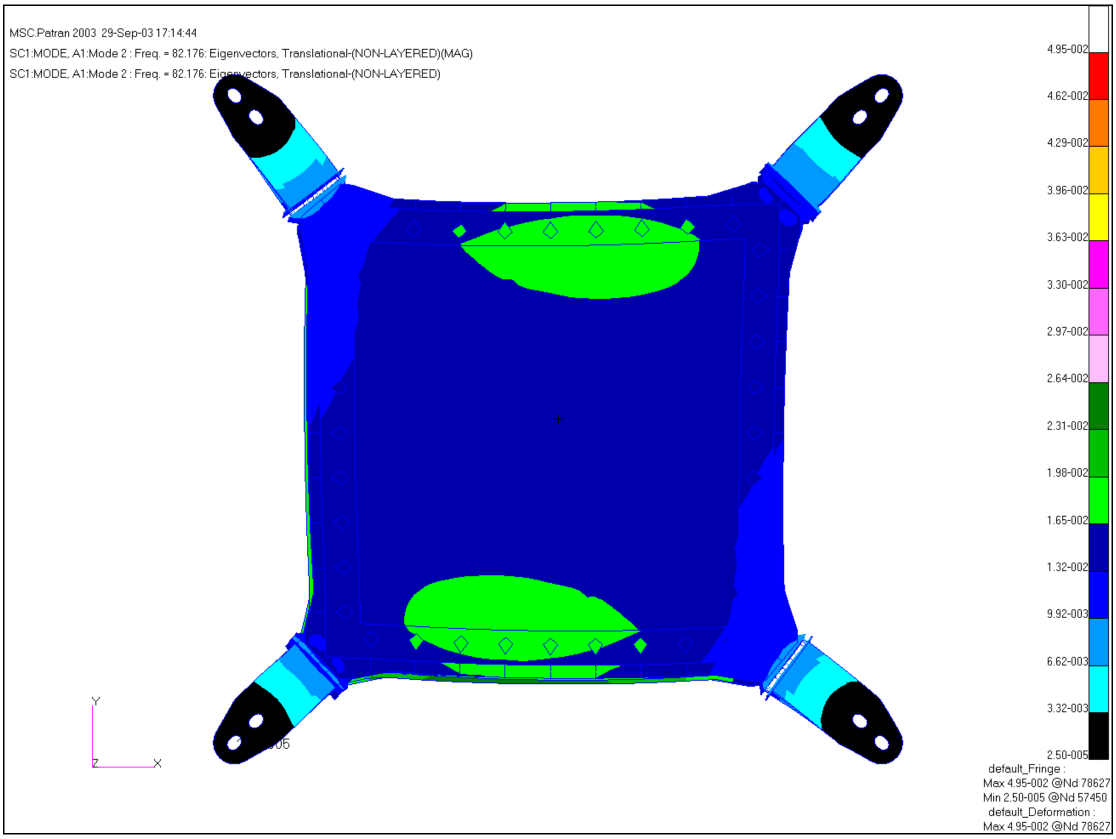


Fig 8.2 Mode shape of ECAL for f2=82.2 Hz (Y direction)

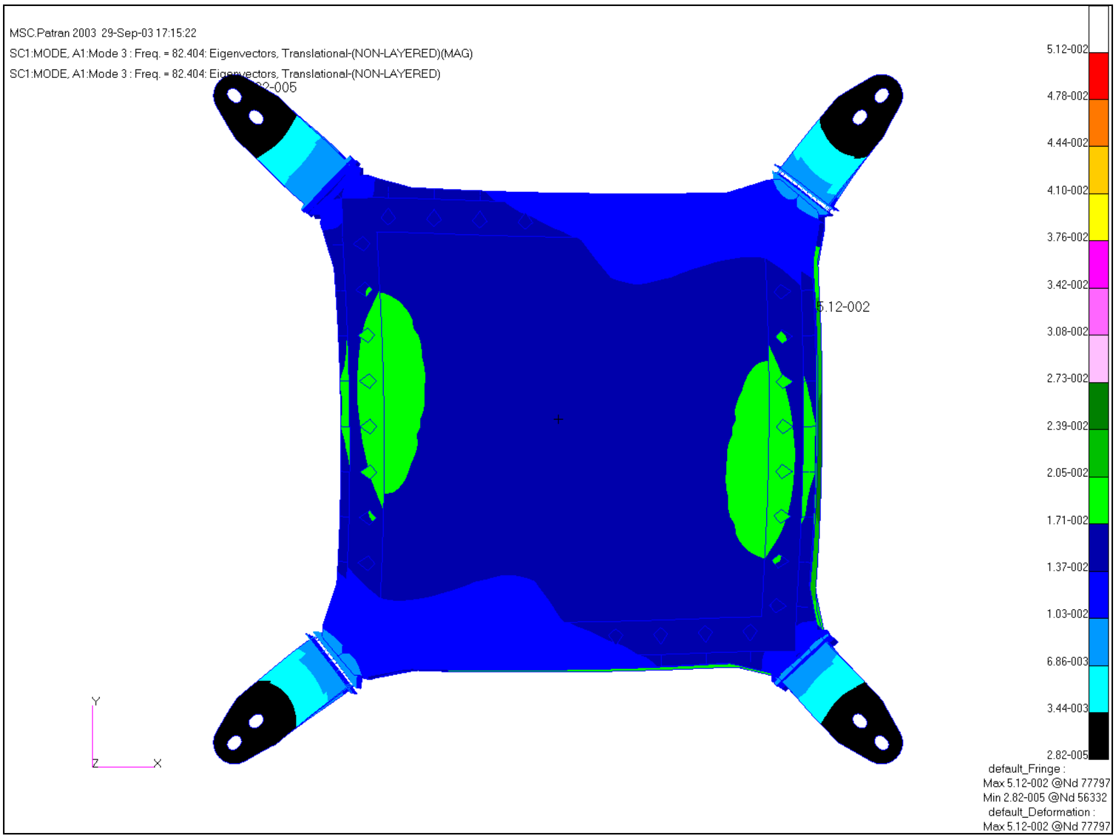


Fig 8.3 Mode shape of ECAL for f3=82.4 Hz (X direction)

5 SINE-BURST TEST CORRELATIONS

5.1 Sine Burst Calculation

In order to do the Sine-burst Analysis, We created a Rigid Frame with Bar Elements to simulate the move of the Vibration Shaker. The ECAL structure is mounted on the rigid Frame by the same manner as mounting on USS2 with slots.

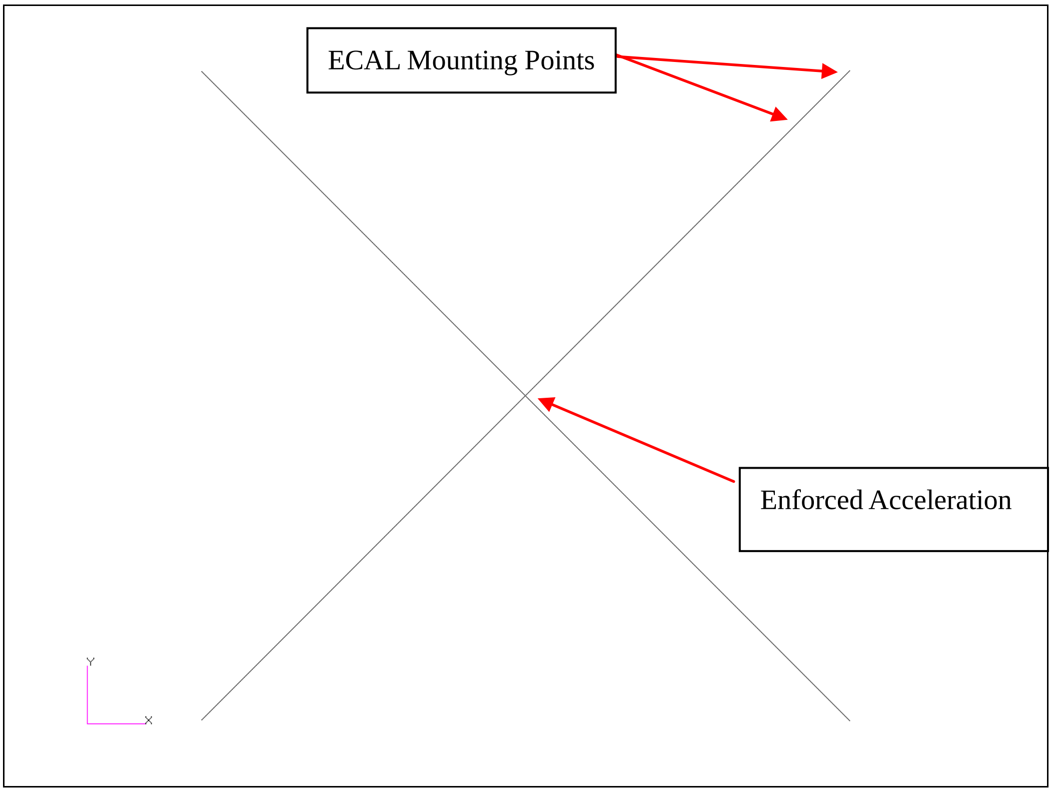


Fig 9 The Frame in the Sine-Burst Test Prediction Analysis

The enforced Acceleration is applied on the center of the rigid frame, which transfer the movement to the ECAL and provide the inertial load on the structure.

The analysis is done along X, along Y, along Z direction separately, the frequency of sine-burst vibration is 17Hz, the enforced acceleration is 12g, as same as in SQ test. Thus we choose the enforced acceleration be:

$$A(t) = 12.0*9.8*\sin(2.0*3.14159*17.0*t). \qquad (m/s/s)$$

The input acceleration curve of sine-burst in x direction on the center of the rigid frame is shown in Fig.10.1.

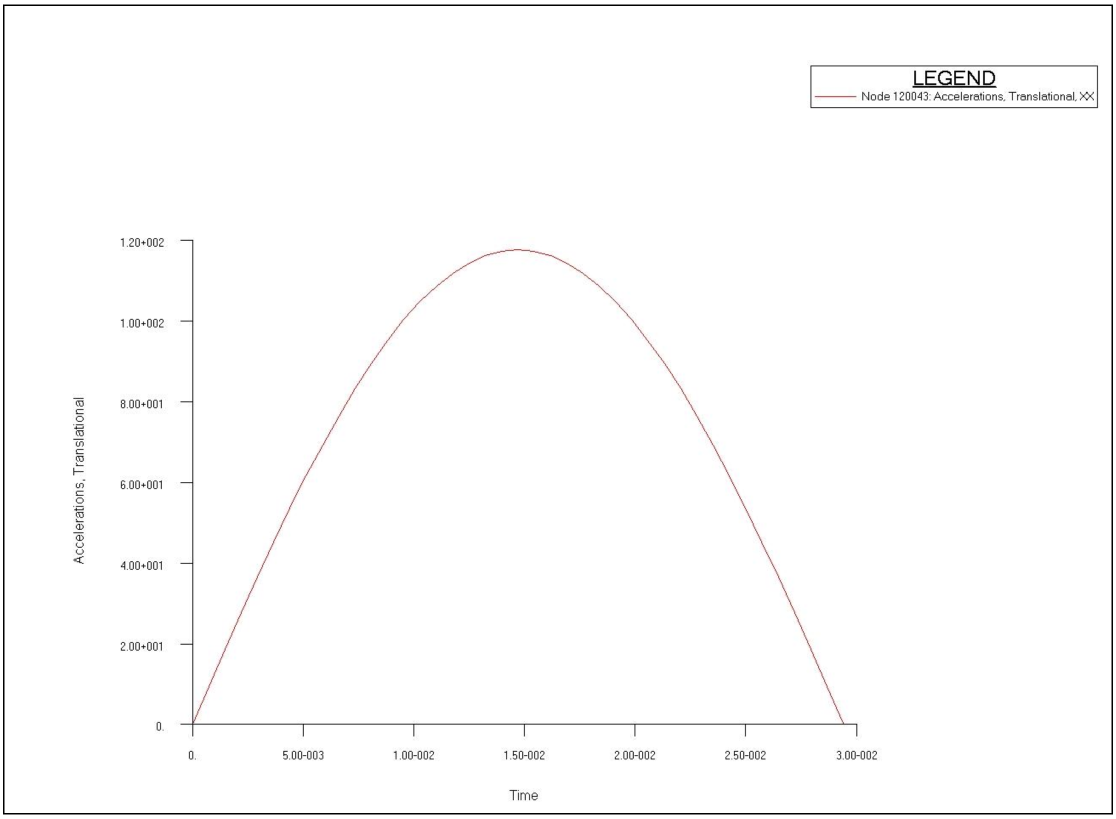


Fig 10.1 Enforced acceleration input curve of sine-burst in x direction

During the sine-burst calculation, damp property of the ECAL structure is optimized to correlate the FEM model. Only half sine wave was calculated, and the maximum stresses peak can be found at in the FEM output results.

The typical acceleration response curve and maximum principle stresses curve for enforced acceleration are shown in Fig. 10.2~10.3. And the Max Principal stress counter of Support, Side-Panel, Bracket, I-Frame, Honey-Plate for Sine-Burst in X, Y and Z direction are shown in Fig11, Fig12 and Fig13.

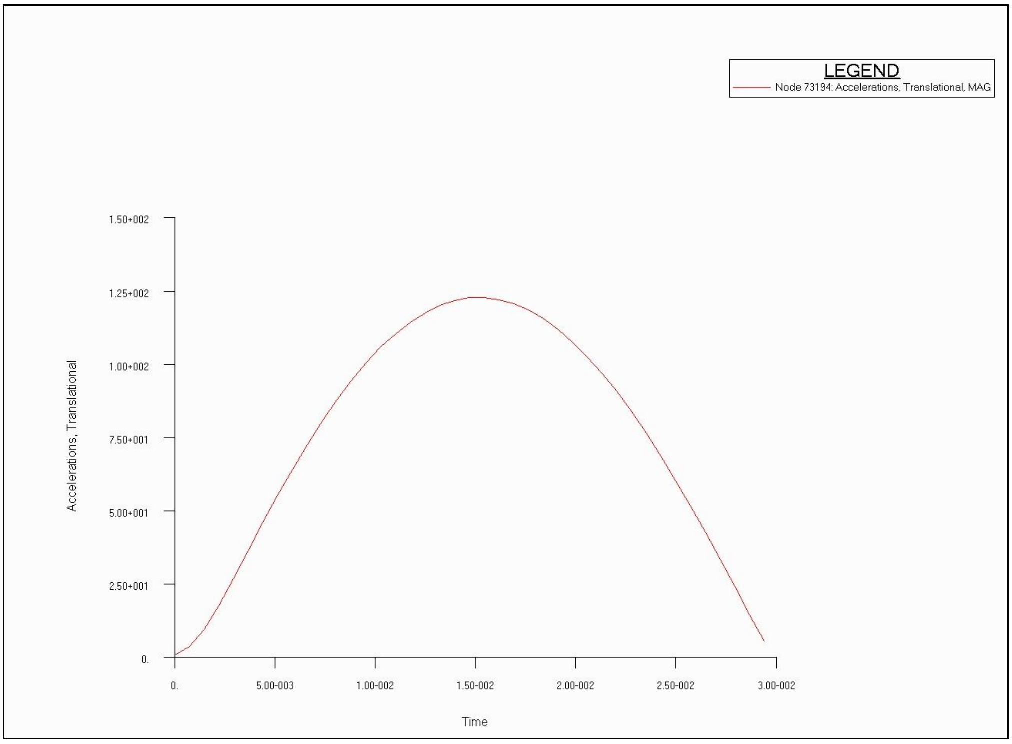


Fig 10.1 the typical acceleration response curve in x direction

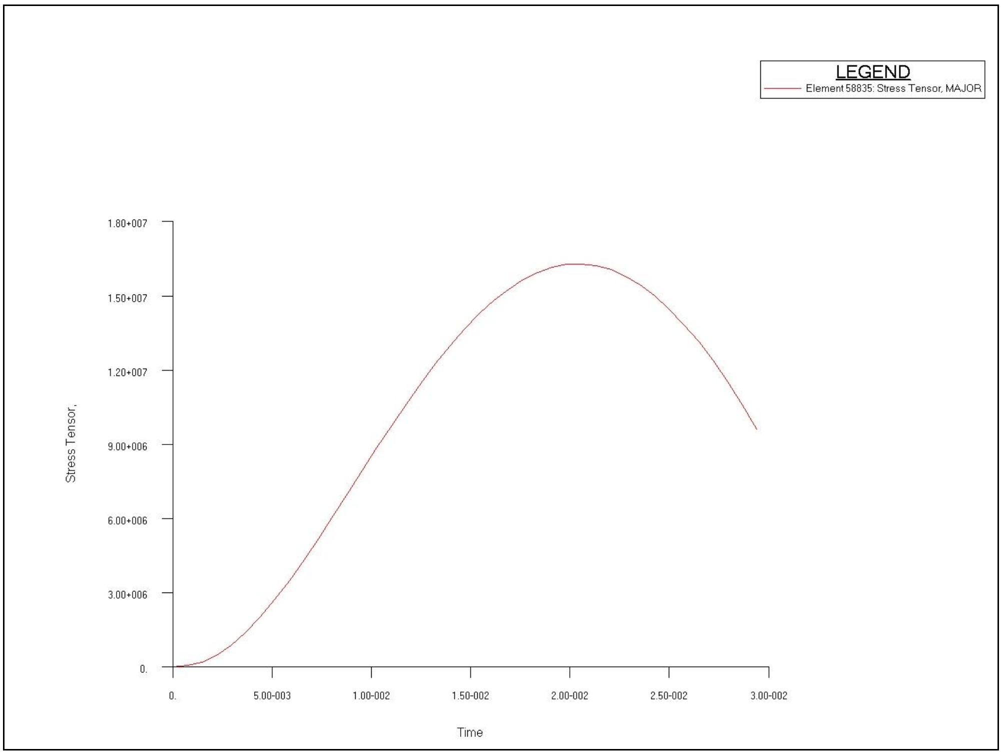


Fig 10.2 the typical stress response curve in x direction

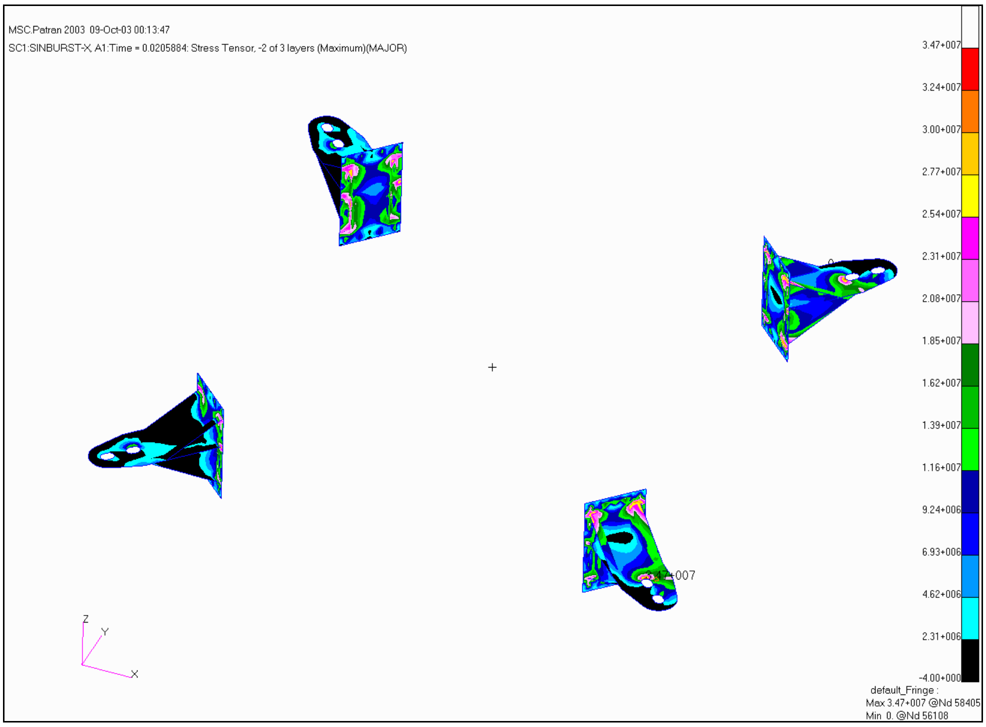


Fig 11.1 Max Principal Stress of Support for Sine-burst-X

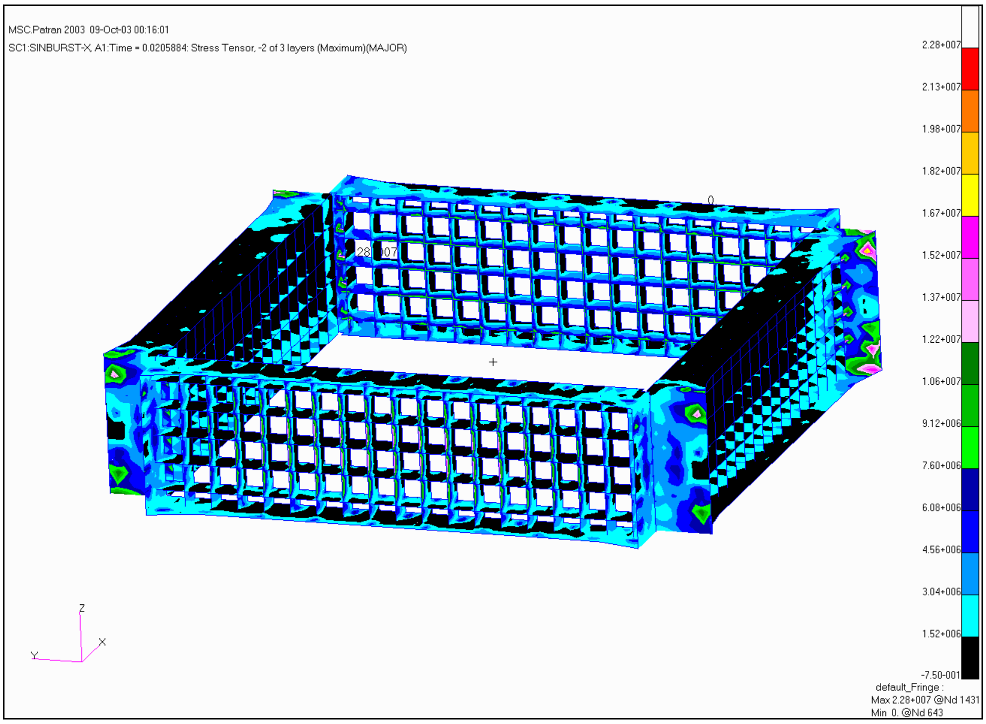


Fig 11.2 Max Principal Stress of Side Panels for Sine-burst-X

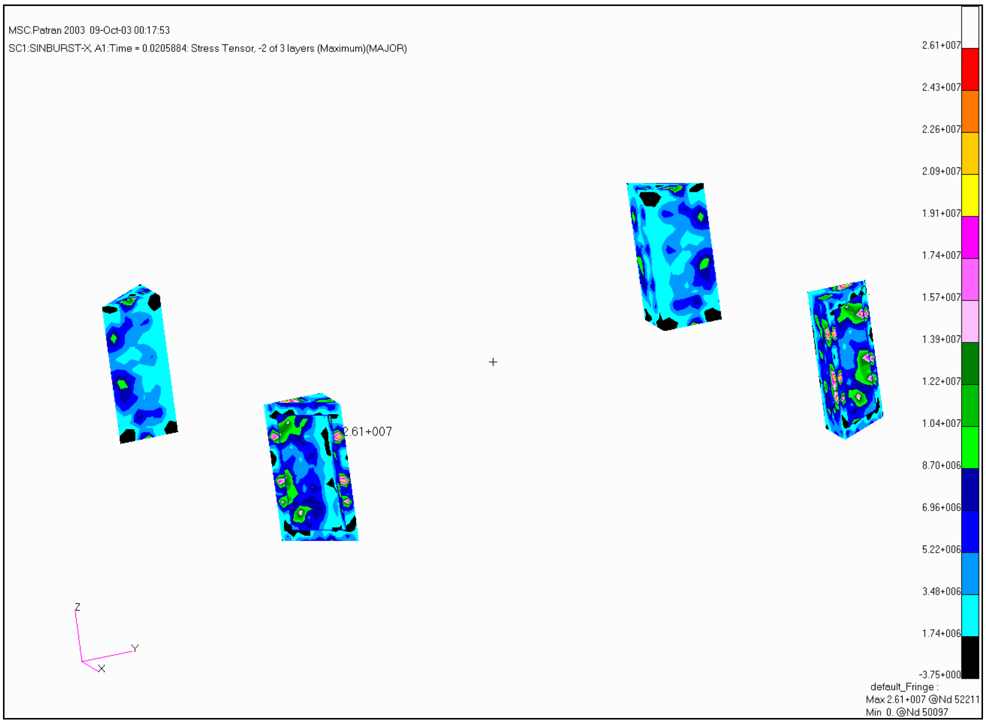


Fig 11.3 Max Principal Stress of Bracket for Sine-burst-X

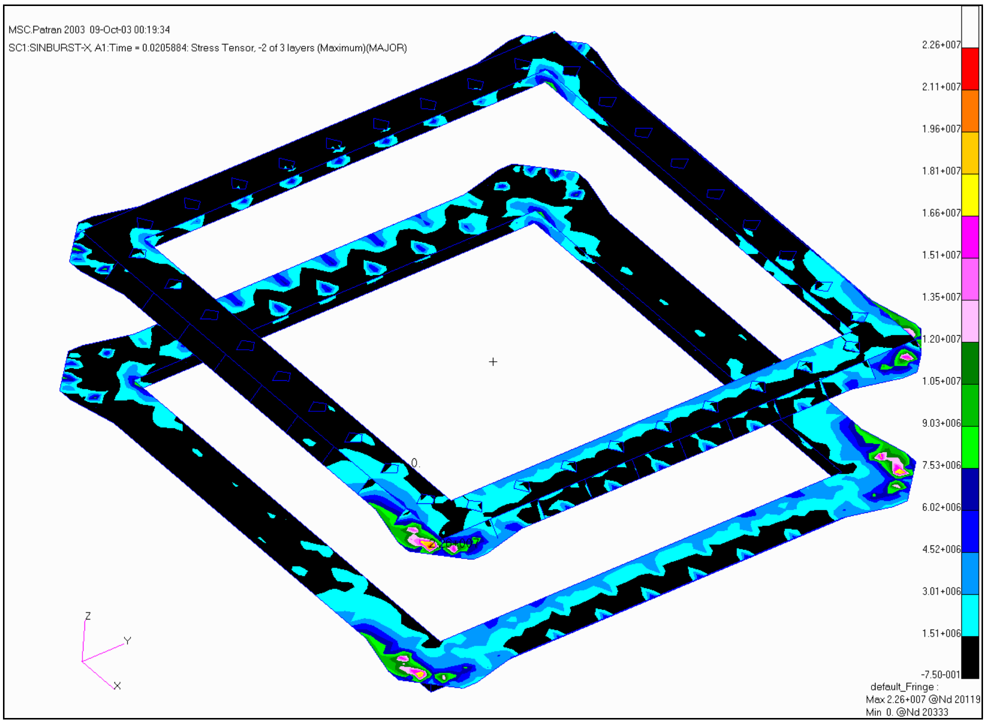


Fig 11.4 Max Principal Stress of I-Frame for Sine-burst-X

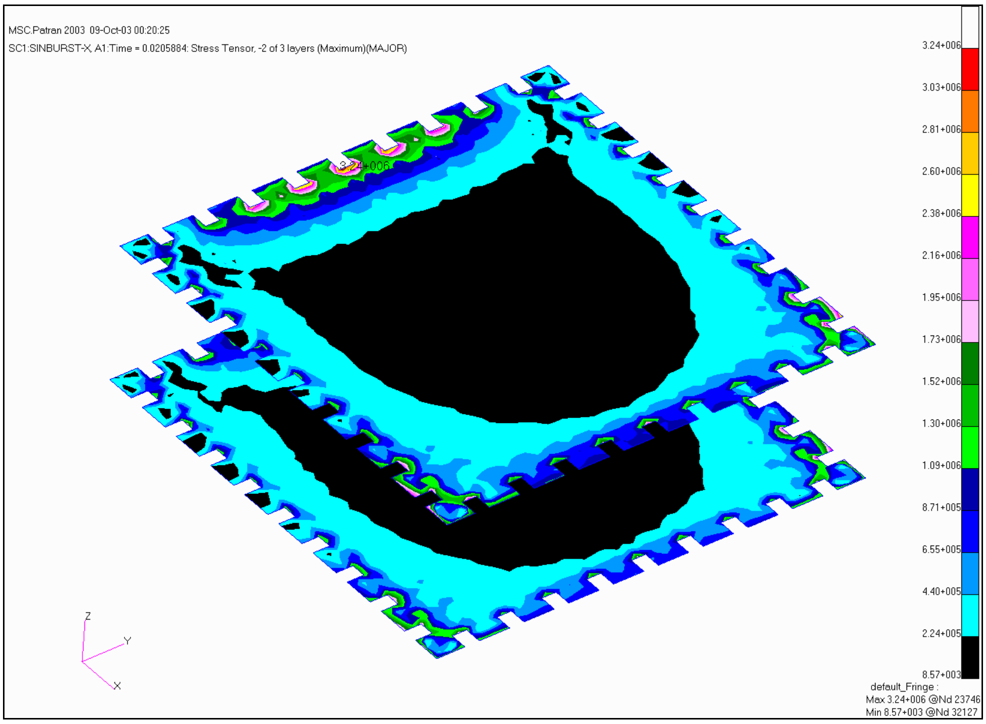


Fig 11.5 Max Principal Stress of Honey-Plate for Sine-burst-X

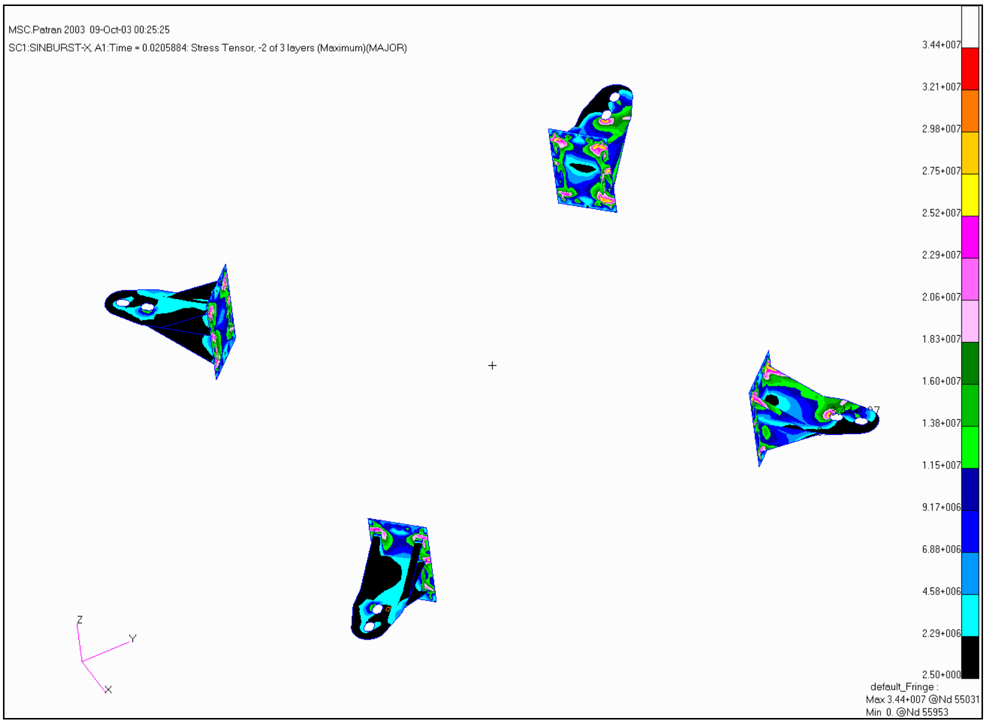


Fig 12.1 Max Principal Stress of Support for Sine-burst-Y

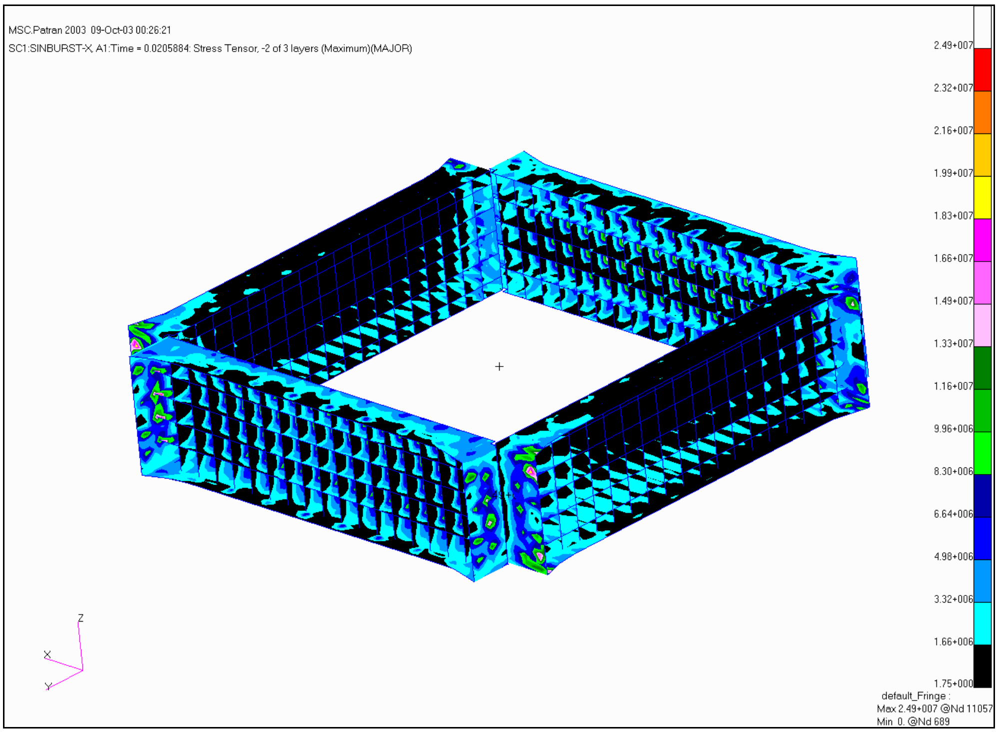


Fig 12.2 Max Principal Stress of Side-Panel for Sine-burst-Y

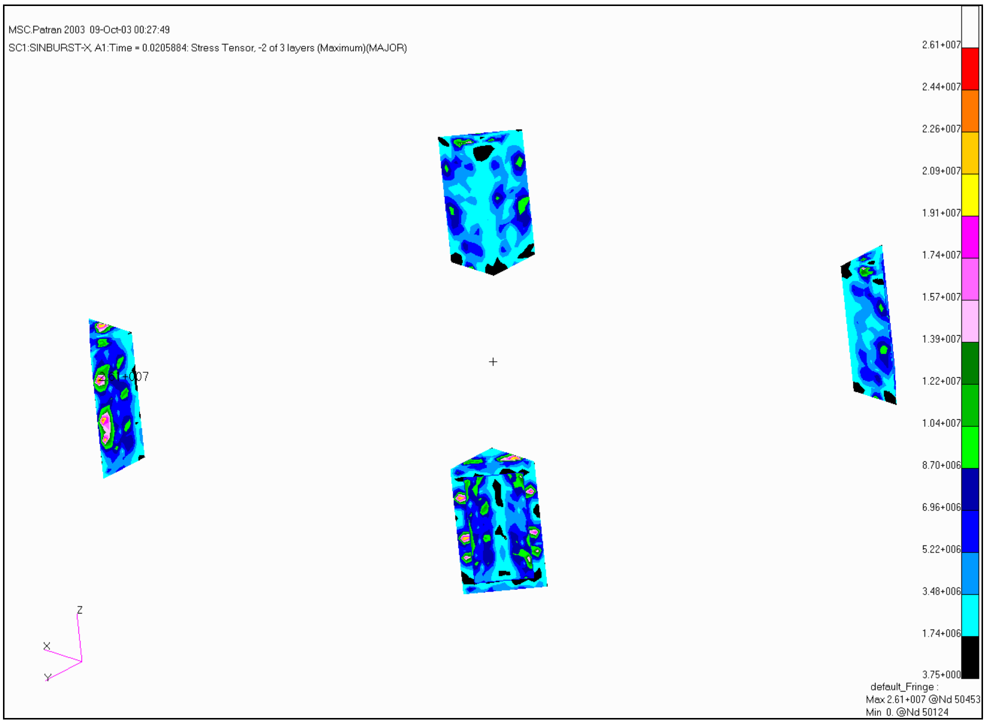


Fig 12.3 Max Principal Stress of Bracket for Sine-burst-Y

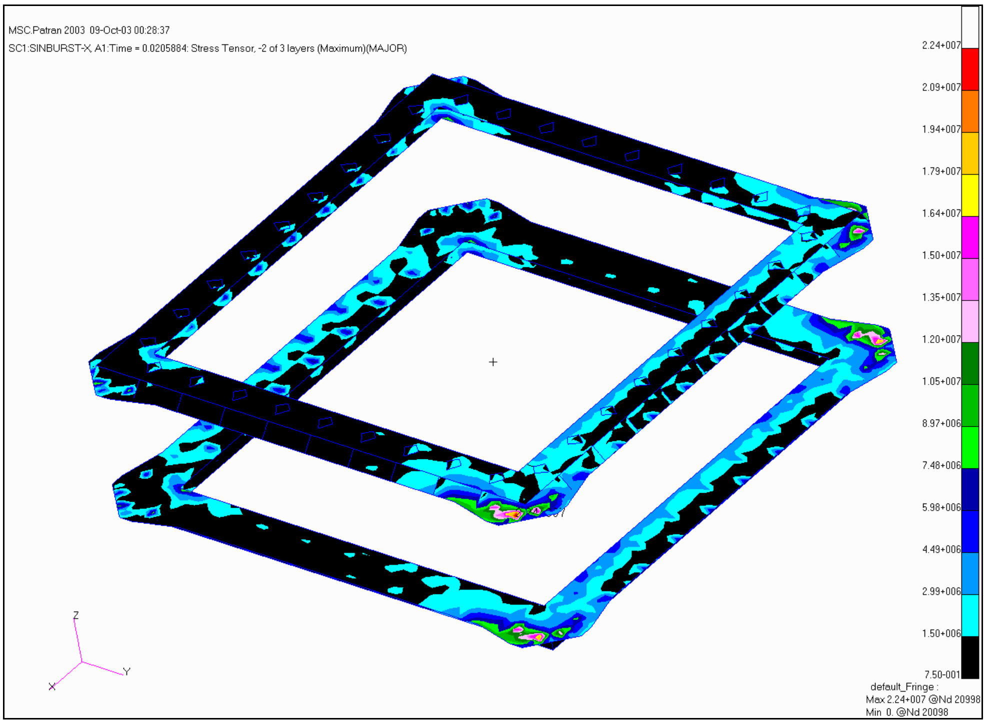


Fig 12.4 Max Principal Stress of I-Frame for Sine-burst-Y

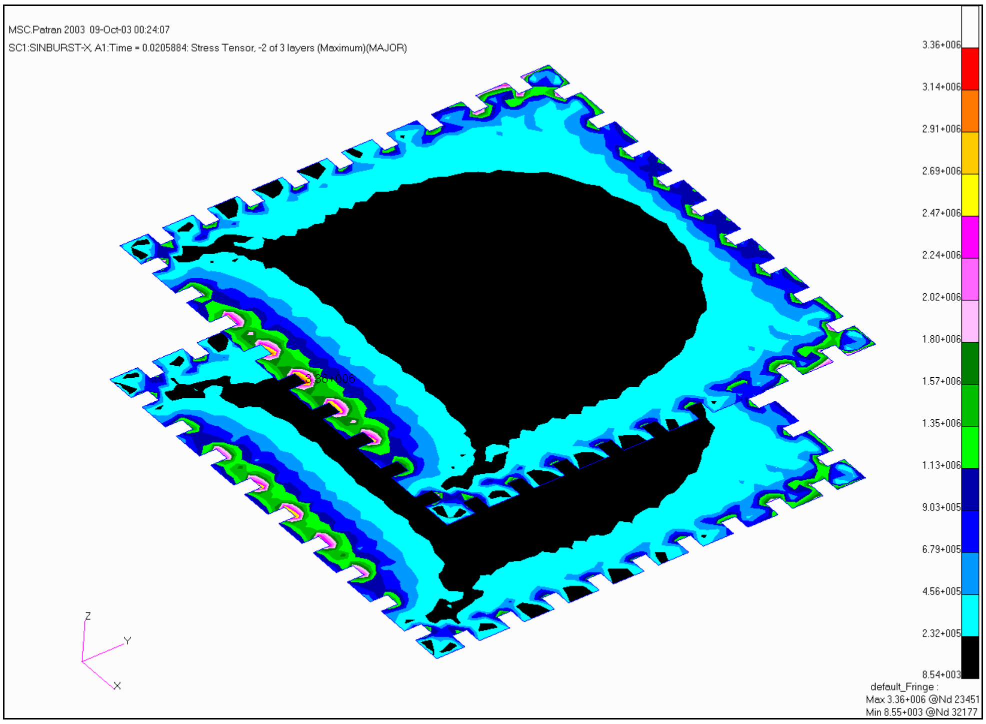


Fig 12.1 Max Principal Stress of Honey-Plate for Sine-burst-Y

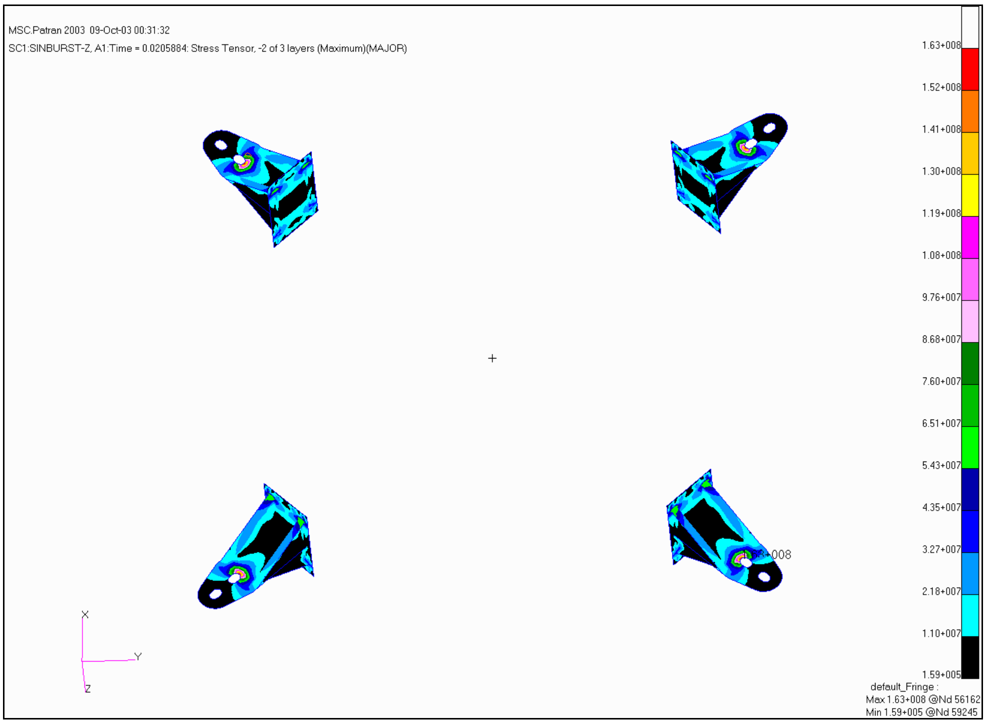


Fig 13.1 Max Principal Stress of Support for Sine-burst-Z

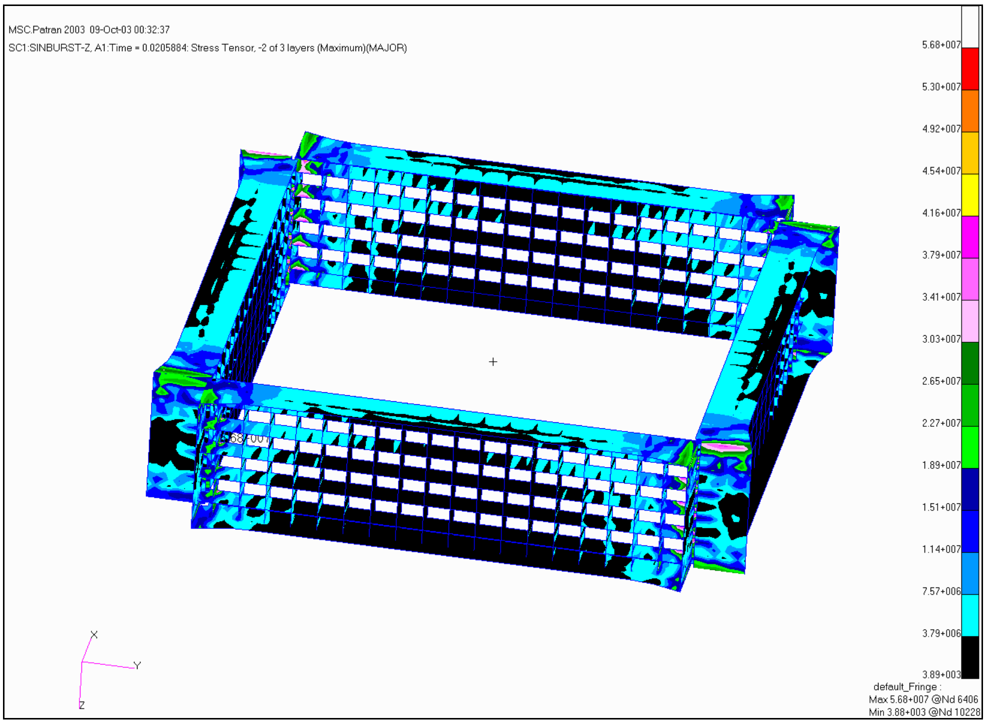


Fig 13.2 Max Principal Stress of Side-Panel for Sine-burst-Z

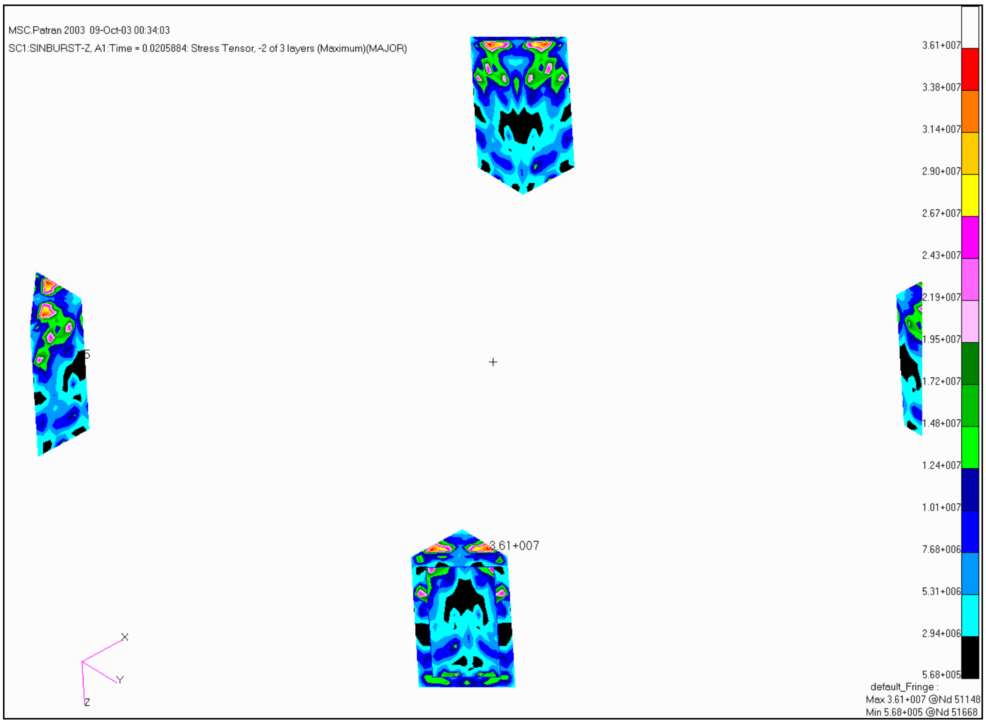


Fig 13.3 Max Principal Stress of Bracket for Sine-burst-Z

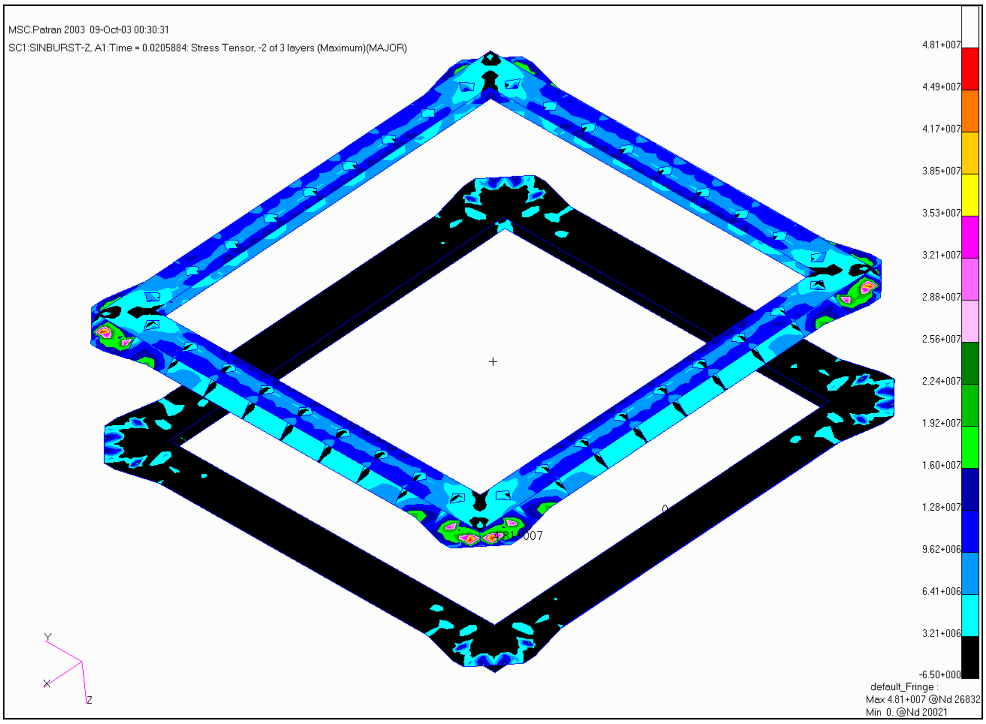


Fig 13.4 Max Principal Stress of I-Frame for Sine-burst-Z

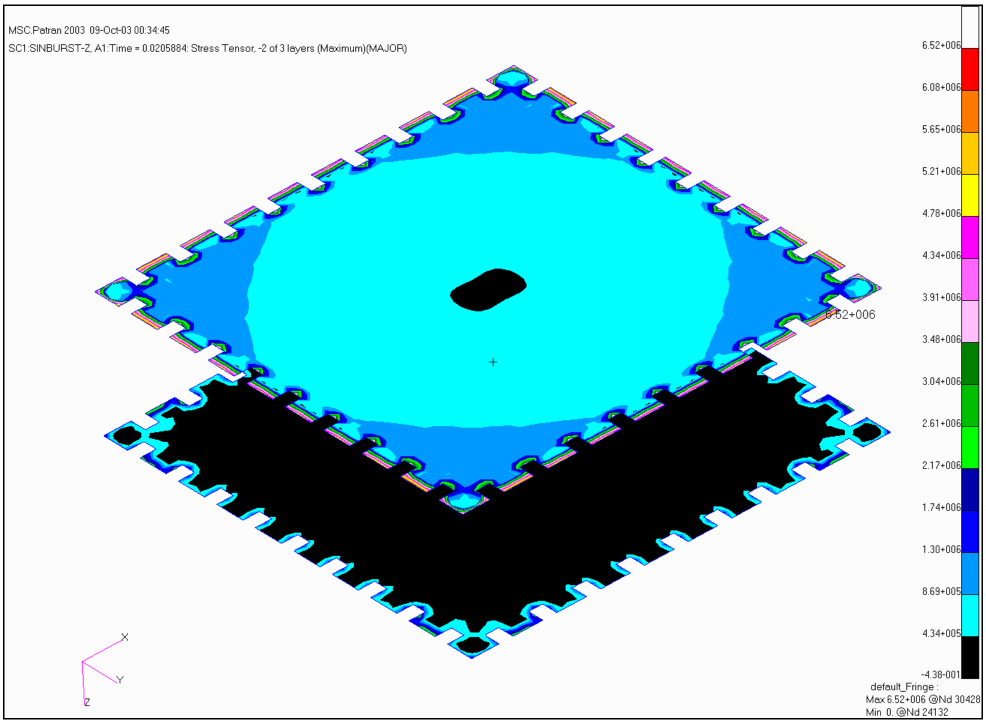


Fig 13.5 Max Principal Stress of Honey-Plate for Sine-burst-Z

5.2 Comparisons of Test data and FEM results

The comparisons of Max Principal for test data and FEM results are listed in Table 11. since the strain gage position is located in a small area, the stresses in Table 11 are the results from the elements and neighbor elements which can be treated as the small area.

Table 11 Comparisons of sine-burst test data and FEM results

Point No	Elm No. in FEM Model	Z direction		Y direction		X direction	
		TEST	FEM	TEST	FEM	TEST	FEM
1	1620	3.71	3.2	1.72	1.58	2.84	3.04
2	11314	1.24	2.05	3.51	4.28	1.34	1.56
3	12559	1.65	0.56	1.28	3.2	2.19	1.68
4	13354	2.61	2.7	1.31	3.41	0.93	1.11
5	14621	1.38	0.4	2.77	1.68	5.21	1.32
6	13303	12.9	13.7	2.89	3.95	16.3	11.7
7	In PMT	1.04	------	15.24	------	1.61	------
8	In PMT	1.32	------	5.49	------	0.62	------
9	Honeycomb	14.36	------	1.19	------	3.52	------
10	32243	17.38	17.3	32.2	12.8	23.8	6.02
11	31106	11.47	17.3	5.36	5.6	25.7	13.5
12	58901	10.40	5	12.6	10.2	13.4	11.6
13	32800	12.89	5.6	2.68	2.77	1.51	0.9
14	honeycomb	21.44	------	10.3	------	20.6	------
15	58919	7.80	9.5	7.49	2.46	5.37	0.66
16	Honeycomb	11.25	------	1.94	------	2.06	------

Note 1: The measure points 9, 14 and 16 are on Honey-Plate, because the ply stress of composite material can not be output from MSC/PATRAN, so these 3 points are not compared.

From Table 11 we can see that the Maximum Principle Stresses are relatively in good agreement between the correlated FEM model and the Sine-Burst test data at most strain gage sensor points.

6 CONCLUSIONS

According to the work described above, the AMS-02 ECAL FEM model has be correlated based on the sine-sweep test data and sine-burst test data. The conclusions are:

1. The first 3 modes have achieved good agreement with the Sine-sweep data in the SQ test along Z, Y, X direction.

2. The Max. Principle Stresses on most measure points have achieved good agreement with sine-burst test data.

3. This correlated ECAL FEM model can be used for the flight load cases simulation of the structure design and for the further weight saving analysis later.